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Section X

Designing Chemically-Resistant Masonry Constructions

Designing with Chemically-Resistant Masonry

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Putting a sheet rubber lining in a steel or concrete tank is pretty straightforward. There are standard specifications to follow. Although the procedures vary to some degree, depending on the type of sheet stock involved, the type of adhesive to be used, whether or not the lining is to be done in the field or in the shop, there are generally published instructions for one to follow.

The principal decision the user must make is the generic type of sheet stock to use—the one best suited to the environment in which the tank is to be employed. He usually can narrow the choice down to a very few candidates through the use of published chemical resistance tables. Thus, a few phone calls will probably determine for him which one of these he will use, and with which supplier/installer he will deal.

If a brick lining is to be installed in the tank to protect the sheet lining or other membrane, the matter becomes slightly more complicated. The designer (usually not the end user) must determine which bricks and mortars are best suited for the environment, and then consider how well the bricks and mortars which he had selected for the environment will mate with each other, and with the sheet lining, how well their coefficients of thermal expansion will mate with that of the steel or concrete tank in which the system will be installed and, finally, which combination will provide the best protection for the sheet lining. If the brickwork does not provide sufficient thermal insulation for the sheet lining, and if the tank is overheated, the sheet lining can be seriously damaged. If the brick lining expands much more than the steel or concrete vessel, it could conceivably rupture the vessel. If it expands less than the vessel walls, so that the wall moves away from it, the wall no longer supports the brickwork, and it can break up and fall in.

The more complicated the structure, the more varied the components that go into its design, the more study the design will require because the designer must consider all possible interactions between these components that can affect the life, strength, stability—the satisfactory performance—of the structure.

THE BASIC PRINCIPLES

There are four basic principles that the engineer must keep in mind in designing a chemically-resistant masonry structure.

(1) *Strength*. A structure composed of "acid brick" or block in any other chemically-resistant masonry unit cannot be reinforced. Although it has good *compressive* strength, it is weak in tension and shear, and depends for its integrity on the bond of the mortar to the masonry face.

(2) *Porosity and/or absorption*. With all chemically-resistant masonry materials under a continuous hydrostatic head or other continuously wet conditions, the masonry units and the mortar used to bond them together will slowly absorb fluids until the structure is saturated. At that point, the underside of the structure is wet with the same chemicals as those on the surface. If the liquid is acid, then acid is present on the underside of the structure. It should, therefore, be clear that although a structure of this kind is strong and can support heavy loads (such as piers and pedestals to support equipment), especially in areas of chemical spillage, this type of structure cannot be used to hold liquid without leaking, nor employed to stop leaks in an existing structure. If a vessel is leaking, the leak cannot be stopped by putting an "acid brick" lining inside of it, or by smearing "acid-resistant" mortar over the area of the leak.

(3) *Brittleness*. Structures composed of "acid brick," block or other chemically-resistant masonry units cannot be flexed or bent (which would cause torsion or shear of joints). They are all somewhat brittle, and if the supporting structure around them bends, they are certain to break. For the same reason, they cannot accept excessive vibration.

(4) *Growth*. Irreversible growth or "swelling." Fireclay or red shale "acid brick," the two most common types of chemically-resistant masonry units, often grow up to 0.16% of any dimension. The reasons for this "growth" are not proven, but experience indicates that it can happen with most "fired" clay brick, unless they have been fully vitrified. Such growth takes place more quickly in cycling, hot, wet environments, and slowest in static, dry, cold exposures. But it does eventually happen to all "acid brick" and other such masonry units made in North America (see Side Effects at the end of this section).

What about monolithics and castables? Depending on the type of components (bonding or cementing agents and fillers), structures made of these materials have many of the same characteristics to a lesser or greater degree.

Occasionally, we find someone designing a structure entirely out of "acid brick" or a monolithic castable. When the structure will be continuously wet for extended periods, such a design will not provide a liquid stop, and the liquids with which it is in contact will very slowly, but eventually, pass through it. (There are a *very* few exceptions: polymer concretes made with very dense, *very* low shrinkage polymeric resins.) If the function of the structure is merely to

supply support, and not protection for some underlying surface, such a design can function satisfactorily.

With these four basic principles in mind, for what purpose(s) would we wish to use chemically-resistant masonry? Here we have four specific uses.

(1) As a load-bearing structure subjected to corrosive chemicals. Examples: (1) Tall brick chimney liners, subjected to corrosive exit gases. (2) Piers resting in corrosive wastes and supporting a bridge, or a piece of equipment. (3) Outer wall of a building (supporting the roof stringers) where the wall is subjected to splash or spray of strong corrosives.

(2) As an internal insulation in a process vessel, reducing the surface temperatures on the membrane to an acceptable level. Examples: (1) Steel pickling tank in a steel mill, lined with rubber sheet. Top service temperature of the rubber 160°F, but bath temperature 210°F. The brick lining provides sufficient insulation to get the surface temperature of the rubber sheet down to 140°F. (2) The same system to protect the membrane in process vessels or (3) to prevent live steam from cutting out the asphalt membrane on a floor.

(3) Protection against wear or abrasion. In use 2 (1), if the "work" (steel plate, etc.) bangs the side of the tank and the brick were not there to protect the rubber, the "work" could cut or puncture the rubber sheet. In use 2 (3), traffic over an asphalt membrane can cut or deform it, but a brick floor over it will protect the membrane from such damage.

(4) If the environment *slowly* attacks either the substrate or the membrane, the interposition of a brick lining between the contained liquid and the substrate or membrane will reduce to a tiny trickle the amount of chemical that reaches the membrane or substrate. Corrosion products, if any, are trapped behind the brick and cannot be washed away to uncover further material to be corroded, so that the corrosion slows down and may eventually stop. Example: In a dished bottom, cylindrical steel tank containing a mixture of acid and oil, the steel was lined originally with sheet natural rubber. The rubber lining swells as the oil enters it, but the brickwork holds it in place until the rubber has swollen into all the pores of the brickwork and blocked them preventing any more of the contained liquid from passing behind the brick.

With the limitations of the basic principles, we note that only the first mentioned use can involve a structure composed of chemically-resistant masonry alone. The other three employ it in combination with a supporting structure (steel or concrete, or very occasionally, wood or plastic), and unless the supporting structure is in itself a liquid-tight barrier to the environment to which the structure will be exposed, a membrane over the supporting structure and under the masonry is necessary. The supporting structure provides the strength to permit the structure as a whole to accept internal loading or surface loading, which would otherwise put the chemically-resistant masonry in tension or shear, and cause it to break up. It must be designed with adequate strength in itself to support, with an adequate safety factor, all the loading to which conditions may subject it, *plus* the weight and stresses of the masonry lining, whether dead loading or stresses induced by growth or thermal expansion.

The design considerations of the supporting structure are covered in earlier sections of the book; consideration of the selection of specific materials is discussed later in this section.

DESIGNING BRICKWORK WITHOUT REINFORCING—CONTOURING

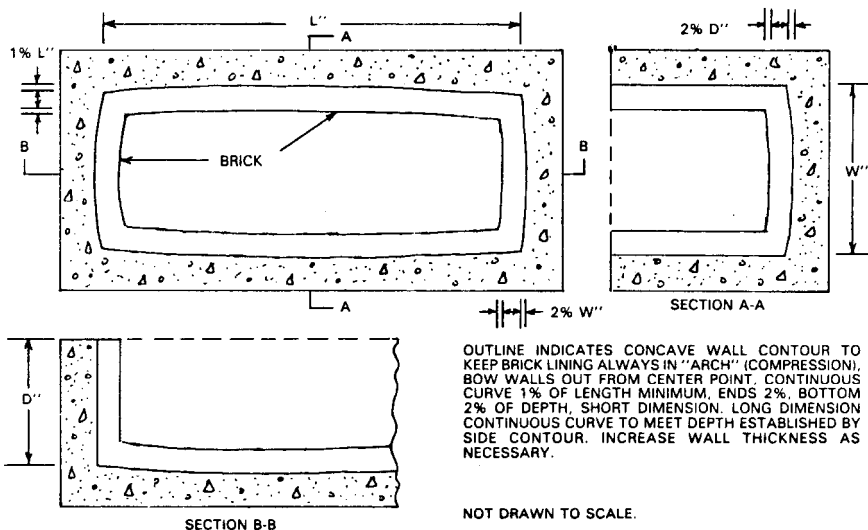
Chemically-resistant masonry cannot be designed in tension because of the problem of reinforcing it. The only bonds that hold brickwork together are the adhesive bonds of mortar to brick, and the tensile strength (cohesion) of the mortar and of the clay (or brick). Various fabrics, such as glass, ceramic, polyester and carbon, may be used to reinforce monolithic surfacing materials; and chopped ceramic fibers, glass platelets and the like are used in some coatings and thin membranes. Expanded metal, wire cloth, and stainless or other types of anchors are used to reinforce or strengthen gunned and cast linings and some polymer concretes. Other polymer concretes have even employed standard steel reinforcing rods, usually with special coatings on the reinforcing. The section in this volume on paper mills describes a hybrid design of hollow tile with reinforcing placed through the tile, a design widely used in paper mills twenty or more years ago, but less frequently seen today.

The use of reinforcing in any of these materials introduces into the structure another generic material with completely different physical and chemical properties. The marriage of the reinforcing to the rest of the structure, while it provides some of the strength that the system requires, at the same time brings additional stress and strain into the system. It immobilizes cure shrinkage, and with a different coefficient of expansion, introduces further stresses with any sizeable changes of temperature. If the stresses resulting from the reinforcing overbalance the cohesion of the system, it will crack even though the reinforcing steel holds the parts together. Therefore, before deciding to use reinforcing, consider whether your purpose can be accomplished without it.

Can tension be avoided? With brickwork, it usually can. By designing so that the brick linings are on the inside of curves (as they are in lining a cylindrical tank), the brick can be kept in compression, provided that the brickwork is sufficiently thick so that the thermal drop through it to the substrate is large enough to keep the substrate (e.g., steel, coefficient of thermal expansion 7×10^{-6}) at a temperature low enough to prevent it from expanding away from the brickwork (coefficient of thermal expansion 4×10^{-6}). In this manner, the brickwork is kept in compression and cannot pull apart. This same principle can be used in designing a large rectangular concrete tank, by changing the straight walls to curves, bowing them outwards at the middle. If this is done, as the brick expand they move ever tighter against the tank wall, kept in compression by this "arch" effect. (See Figure 45-1 and Drawing 1.)

Conversely, if the concrete contractor is careless, and the braces of his forms slip, the weight of the concrete can bulge the wall *inward* at the center—perhaps not everywhere, but in only one short section. If this is not corrected, and if the membrane and brick are laid over this reverse curve, as the brick grow they will push into the tank, away from the supporting wall, so the brick will separate from the membrane and wall, and eventually fall in.

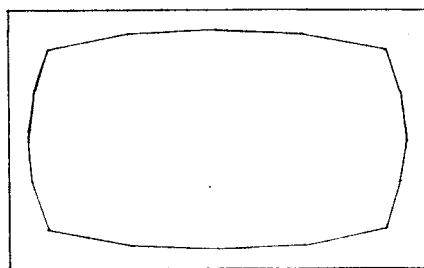
No concrete contractor likes to use curved forms to build contoured vessel walls. This slows down construction, reduces productivity, and thus increases costs. Therefore, many will decide to bid the construction with straight instead of curved walls in the hope they can argue the purchasing agent or contracting officer out of them. If successful, they will pocket a larger than average profit.



Drawing 1: Concrete vessel outline, walls and bottoms contoured. Used by permission of the Pennwalt Corp.

If the customer insists, however, they will lose money, and so they will try to complete the work by various ruses.

One way they may try to get around this design—and unfortunately it has been suggested by some engineers in the past, so that it appears in a few technical papers—is to make the curve with a series of straight forms placed together at a slight angle. See Drawing 2.



Drawing 2

This results in a polygon instead of an elliptical shape. The designer should remember that the whole purpose in curving the walls is to create an arch over the membrane so that, as the masonry grows, it will arch against and press into the membrane uniformly, tightening itself against the supporting structure. The reason for this design is to eliminate the flat surface because if we have a flat surface, we can have lateral growth movement over it, restrained only at anchor points—in this case the angles between the flat surfaces. Just as the brick will grow and

bulge up away from a flat floor, they will eventually bulge away from the flat sections anchored only in those angular points. If the contractor follows such a design, the surface is *not* acceptable for the installation of the brickwork as it stands. The angles must be filled in, and the continuous, smooth curves established by re-surfacing the structure.

In an existing rectangular vessel, the curves may be accomplished by "gunning" concrete into the four corners and building the curves into the walls using gunite techniques, then trowel-finishing the surface. A similar procedure may be followed to correct the flat areas if flat forms are used. But the designer must bear in mind that, unless this is done, the design shown in Drawing 2 is unacceptable.

Naturally, when designing a long brick-lined trench, the walls cannot be "bowed." A succession of bows would merely result in the brick separating from the walls at the juncture of the bows, although this tendency might be reduced if the bowed sections were short and "thrust blocks" (see later in this section) were used at the juncture point. However, the expense of such formwork and the laying of the brick would be uneconomical when compared to the cost of construction with dead straight walls with expansion joints every 15 feet. The designer, however, should warn the contractor as part of his specification that after forms are stripped, the concrete surface shall be checked by an independent inspector, and any bulge found in the wall—any surface bulging inward out of dead straight—must be removed by chipping or grinding before the concrete can be accepted.

On a flat surface such as a floor, if a sufficient number of expansion joints of adequate width are not provided, the expansion joints will close up and, as the expansion continues, the brick will heave upward off the flat surface. In older designs, dating back to the turn of the century, it was often suggested that when it was impossible to "bow" the straight walls outward, a design "battering" the walls by sloping the plane of them outwards about 7° from vertical should be followed. In that period, there was no concern with the irreversible growth of brick which was first noted about 1954. It is presumed that gravity was supposed to hold the wall down if it expanded thermally into the expansion joints. A moment's thought, however, will tell today's designer that with today's irreversible growth, if the brick on expanding, heave off of the floor, they can also heave off of the battered wall. However, as long as the walls are dead straight and the designer has supplied adequate thickness to support the free standing wall on its base (see below) and an adequate number, size and placement of expansion joints, the problem of movement away from the concrete supporting walls will not arise.

When designing a floor, we can provide for expansion—dimensional changes—of the brickwork with expansion joints. This same rule is followed in designing the bottoms of tanks or the bottoms of trenches. If the liquids that will be held in the tanks, or which will flow through the trenches, contain oil, greases, fats, solvents, for which there is no adequate expansion joint sealant, then we cannot plan to use this method of providing for the brick movement. In a tank, we can contour the bottom—that is, dish it. If we do this, just as we have contoured the walls, we will keep the brick in "arch" configuration and keep it pressed tightly

against the membrane and, hence, against the supporting wall, eliminating the expansion joint.

With a trench, if we curve the bottom, so that it is deeper in the center than at the sides, we will not require a longitudinal expansion joint. We will, however, if the walls are not contoured, require an expansion joint across the trench—down one wall, across the bottom, and up the other side, on the average of every 15 feet, as well as at other points designated below, under "Expansion Joints."

STABILITY

When chemically-resistant masonry is installed as a liner inside a membrane-lined supporting structure, the chemically-resistant masonry must be free to move or slide on the surface of the substrate, relieving stresses, expanding or contracting with thermal changes, independently of the substrate, if it is to retain integrity. This means (1) that there cannot be anchors penetrating both substrate and chemically-resistant masonry lining. If such anchors were to be employed, any corrosive in the environment could follow the shaft of the anchor back through the membrane and into the substrate. Further, if the substrate has a different coefficient of expansion than the chemically-resistant masonry, and it usually does, then these anchors would prevent the chemically-resistant masonry from expanding or contracting at a different rate than the substrate, and if one of the elements of chemically-resistant masonry is "acid brick," it would create stresses within the structure as the brick would try to expand in their irreversible growth, which differential expansion is provided for by expansion joints. In order for this movement to be free of stress, and as uniform as possible, (2) the surface of the membrane-covered substrate must be as smooth as possible, and any obstructions must be suitably provided for. This second point will be discussed later.

In cylindrical or curved body vessels or structures, stability of the lining is also obtained by the arch effect which has eliminated the need for reinforcing. However, in straight line designs, as in rectangular walled vessels or trenches, stability must depend on the ability of the structure to balance upon its foundations, just as does the wall of a brick house, or any other masonry structure. This means that as the chemically-resistant masonry wall gets higher or longer (or the lining of a vessel gets deeper or longer), its thickness must be increased so that the wall retains stability. While no one has found a way to compute the exact thicknesses that are necessary to stabilize specific heights and lengths of brickwork, some rules of thumb exist (see Table 45-1) which have received general acceptance, and which, if followed, can be considered adequate. This does not mean that using somewhat lesser thicknesses insures failure, nor that success is guaranteed if these rules are followed. It *does* mean that past designs that followed these rules were usually successful, while ones that employed much less thicknesses had considerably shorter lives or required considerable maintenance.

It should be noted that, if interlocking expansion joints are to be used, it is generally advisable to go to an 8" lining. The reasons for this will be discussed under that heading.

Table 45-1: Thicknesses Needed to Stabilize Heights and Lengths*

Depth (ft)	Length (ft)	Thickness (in)
≤1	≤30	2-½
≤2	≤15	2-½
1-2	15-30	4
2-6	≤15	4
2-6	>15	8
>6	any	8-12

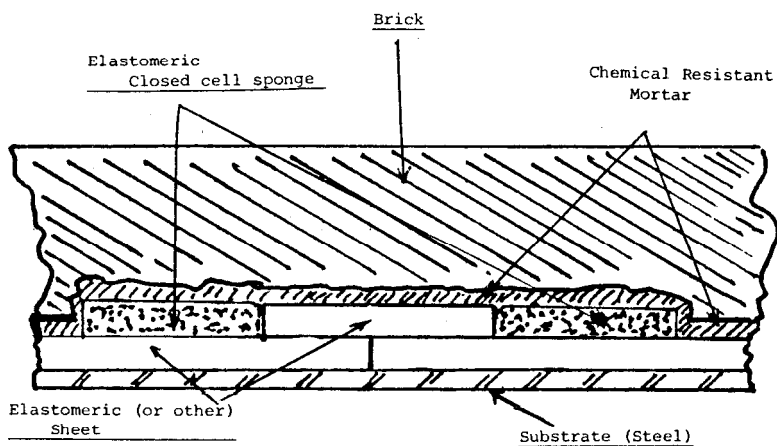
*For extremes of length and depth, greater thicknesses are advisable. From *Chemically Resistant Masonry*, Walter Lee Sheppard, Jr., 2nd Ed., Marcel Dekker, NYC (1982).

The second point mentioned above, that of providing for obstructions to movement that cannot be eliminated, requires further consideration at this point. Let us consider, for instance, the selection of a sheet rubber lining as membrane. The application of sheet linings means that, at regular intervals, there will be joints between sheets. These may be laps of one sheet over the adjacent one, or butted edges with a seal strip on top of the butt joint. In either case, there is a double thickness of sheet at that point. If a brick (or other chemically-resistant masonry) lining is applied directly over this sheet lining, these ridges will act as anchors, protruding into the mortar joint between the brick and the membrane. If the chemically-resistant masonry lining tries to move under such conditions, one of two things can happen. The chemically-resistant lining can tear the joint in the membrane, causing leaking. This is the most likely result. If the membrane is strong and the chemically-resistant masonry lining is thin or weak, the chemically-resistant masonry lining can crack and pull apart. To prevent damage to the structure, the protrusion of the membrane lap must be provided for. Drawing 3 shows how this is done. Two sponge pads of the same thickness as the lap or protrusion, and at least 2" wide, are cemented to the membrane, one on each side of the protrusion prior to the installation of the chemically-resistant masonry linings. The brick (or other masonry unit) that is to go over this joint must be notched—a large enough notch to cover the combined lap (or protrusion) and the sponge on each side of it—so that when it is mortared in place, the masonry can slide (move in either direction) by compressing the sponge pads. If this is done, the chemically-resistant masonry lining will be able to slide one inch in either direction without hanging up on the protrusion.

We have earlier supplied the reason why "battering" is not a satisfactory way to resolve the problems of irreversible growth. Another idea favored by many designers is to design the flat concrete wall with pilasters protruding from it at regular intervals or, alternatively, to leave the wall dead flat but to build pilasters into the brick lining to give the wall greater stability.

If the pilaster is built into the concrete wall itself, it acts as an anchor and prevents movement over it. If there are no expansion joints in the brickwork itself, this design will require sponge expansion pads on both sides in just the same manner as on both sides of the cap strip in the sheet lining (see Drawing 3) if the brick is not to heave off the wall and fall in. The detail over the face of the pilaster will be even more difficult because it will have to include an expansion joint,

which will introduce weakness into the wall at that point. The alternative is to place expansion joints in the brickwork midway between all these pilasters and to leave the brickwork anchored on them as points of no movement—all of which is as expensive as, or more expensive than, contouring the concrete.



Drawing 3

Frequently designers seek to resolve this matter in another manner—by building a brick pilaster into the brick lining. A moment's consideration of this idea will quickly tell the designer why this will not work. The *only* strengthening the pilaster gives to the lining is the vertical weight of the brick in it. Standing by itself, only the weight of the brick holding it in place has any stabilizing effect. If the column stood alone—to a height of, e.g., 10 feet—a strong man should have little trouble pushing it over by pressing against the top bricks in the column. Figure 45-6 shows how little stability the pilaster has provided in one case where the brick is pushed away from the wall at the furthest point *exactly* at the pilaster, unbalancing the pilaster inward.

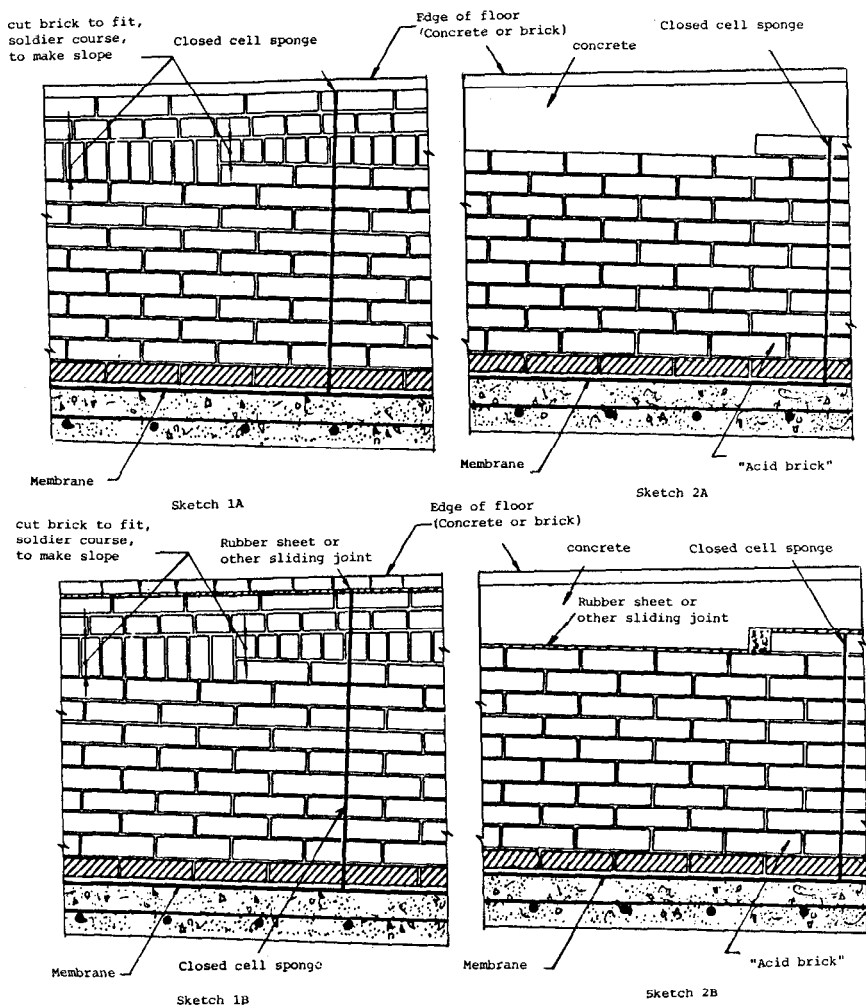
EXPANSION JOINTS—GENERAL

On any structure composed of two or more dissimilar components, there will be a difference in the coefficients of thermal expansion of those components. Take, as an example, a steel tank lined with a sheet rubber lining and inner-lined with 8 inches of "acid brick."

As the internal temperature rises to 200°F, the brick try to expand. The brick act as thermal insulation so that if the tank is standing in a room with an ambient temperature of 70°F, the steel shell temperature will be approximately 120°F. Although the steel has a much higher coefficient of expansion than the brick, it is only 50° hotter than it was when the brick lining was installed at 70°F. However, the brick (and mortar) on the inside face are now 130°F hotter than when they were installed, and they will expand accordingly. In addition,

the irreversible growth mentioned earlier must be provided for. Therefore expansion joints are needed to permit this expansion to take place without disrupting the steel shell of the tank. This means that some compressible joints must be installed at appropriate spots to allow the brick to squeeze together. But since the steel shell and its rubber lining will be solid—without expansion joints—if the brick on both sides of the compressible expansion joints are to move together closing the joints, then the brick must slide over the face of the rubber lining.

This is the first law of expansion joints—every expansion joint in chemically resistant masonry must end in a sliding joint or another expansion joint. If it is not so designed, the expansion joint will not function. See Drawing 4 of the wall of a brick-lined trench, below.



Drawing 4

The upper right-hand sketch shows the way a draftsman first designed the expansion joint. Note that the joint is totally immobilized because where the joint ends in the concrete above the brick lining, the concrete abuts the brick and holds the top course of brick in a fixed position. If the top brick cannot move, then neither can the brick below it.

In the upper left sketch, the brick on the left side of the expansion joint cannot move to the left because to do so would force it into the capping on the top of the trench wall. It will, however, be able to *close* the expansion joint—moving to the right if a shear plane—a sliding joint, such as a Teflon sheet, exists under the capping. None is shown in the drawing.

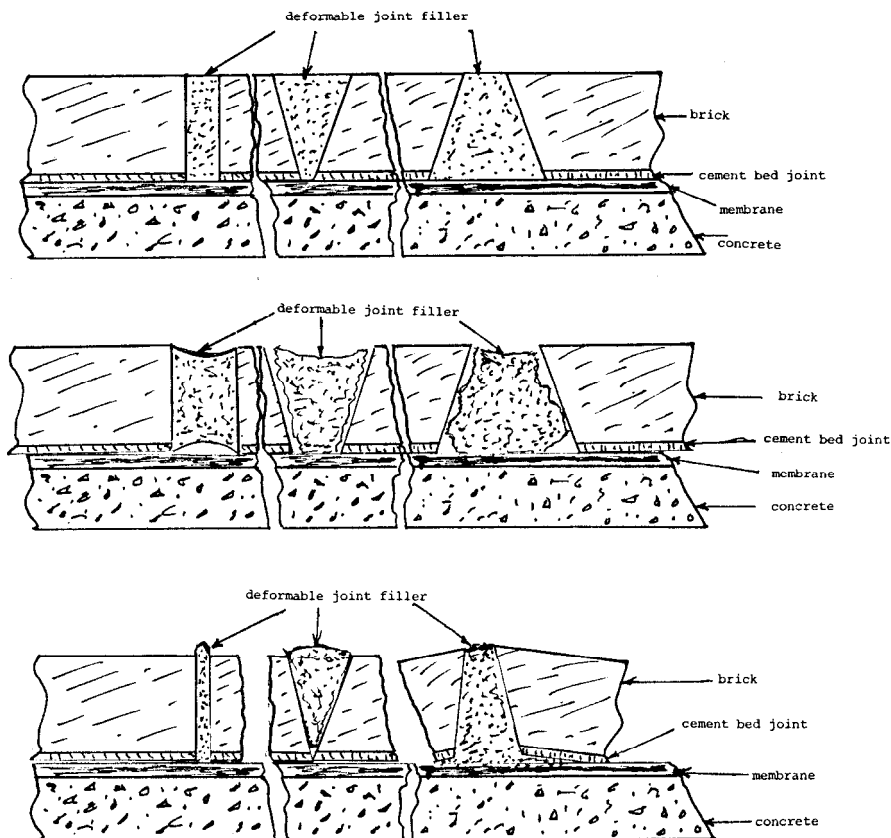
The lower right hand sketch shows the corrected design, freeing the brick to move in *both* directions, and the joint to open and close. Note that there are examples of both the compression joint and the sliding joint. The lower left sketch shows the sliding joint necessary under the cap for the joint to function in this design.

There is a great difference between a *compressible* expansion joint material and a *deformable* joint material. A true compressible material is one that can be squeezed together without extruding from the joint. The majority of the useful compressible joint fillers are closed-cell sponges or foams of the type best suited for the environment in which they will be employed. (They are required in totally enclosed joints where materials may not be extruded without disrupting the masonry.) They are installed by compressing them about 25% of their volume and then sliding them into the joint.

Deformable materials, on the other hand, are materials of a soft or putty-like texture, of a constant volume. When this type of material is used to fill a joint, as the joint closes, the material is squeezed upward and extruded out of it. As the joint opens, the deformable material is sucked down into it (see Drawing 5).

Compressible materials rarely have a good bond to the sides of the joint but, if installed under pressure, will expand to release that pressure if the joint opens, or squeeze together if it closes. Without a good bond to the joint sides, this type of filler is rather easily penetrated by contained liquids. It is, therefore, common practice to fill the joint to within $\frac{1}{4}$ in. to $\frac{1}{2}$ in. of the top with the compressible foam, then seal the top space with the deformable sealant, applied in putty or fluid form and bonded to the sides of the joint. It is important that the sides of the joint are truly vertical, at 90° from the floor surface, so that as the joint opens or closes, the movement is at right angles with the sides.

If the sides of the expansion joints are not truly vertical, so that they slope either inward or outward, as the joint opens the filler material in the joint will be pulled away from the walls diagonally—a tearing motion to restrain which requires far greater adhesive strength than does the pull at right angles. The result will be the rather early disbondment of the joint filler. If the joint closes and the sides are sloped inward (from bottom to top), any deformable material in the joint will be squeezed downward, resulting in an upward pressure on the brick around them, tending to lift the brick off the membrane. If the sides are sloped outward (from bottom to top) and the joint closes, the filler material is forced upwards and in shear along the sides, causing a loss of bond, eventually resulting in the filler popping out of the joint.



Note dimensional changes of deformable filler in each case, as joints close, and as joint opens.

Drawing 5

If the joint is made in this manner in a food plant, such as a dairy, and milk (or other fluid food) penetrates the joint, it will form a static pool on top of a properly installed membrane, in the area of the joint, and slowly become rancid or ferment, creating odors, and causing troubles with the food inspector. For this reason, it is common practice in food areas to fill the entire joint with deformable material rather than use closed-cell sponge at the bottom, leaving no void in which the milk (or other food materials) can collect. As the joint closes, the sealant is extruded at the joint top. Any excess can be removed with a sharp knife leaving the joint full, but not protruding.

If there is no membrane under the joint, as in an expansion joint in a tile floor laid directly over a crack in the concrete slab, the deformable sealant will adhere to the bottom as well as the sides of the joint. If this happens, the deformable material will not function properly. The joint cannot open without pulling the filler off the sides of the joint at the bottom, or close without tearing it loose at the bottom and top of the joint.

Where a masonry surfacing is laid over a membrane (as for instance brick over a hot asphalt-coated concrete floor), the membrane provides the sliding

joint. The expansion joints in the brickwork need only to be compressible closed cell foam or sponge, topped with a deformable sealant, placed at adequate distances apart to accommodate the brick movement which will be the algebraic sum of irreversible growth and thermal expansion. Normally, this means with "acid brick," the placement of expansion joints on floors at a 15 ft. to 20 ft. distance apart depending on the range of temperatures to be accommodated. However, it must be remembered that if the area involved is broken into smaller units by pump bases, building columns, piping through the floor, drains, etc., the brick cannot move at the point where the interruption occurs. These fixed points, then, will require an expansion joint between them if "heaved" floors are to be avoided. If such fixed points are single interruptions in an otherwise continuous floor plane, they can be handled simply by isolating them by placing a single continuous expansion joint around them.

Where the space between such fixed points is 3 feet or less—for instance, two pump bases—and there is little likelihood of temperatures cycling over 20° to 30°F, it is possible to dispense with an expansion joint between them. However, if there is a steam jet that can play on the floor, or the possibility of the spillage of very hot, possibly boiling, liquids, then an expansion joint should be installed even in that small a space. The rule to follow is, install an expansion joint over (1) all points of movement: expansion, control or construction joints or moving cracks in the substrate, (2) around or between all fixed points, including changes in direction or elevation of trenches *except* drains.

Drains are fixed points, but they are at the lowest point in a floor, and expansion joints are the weakest, and most easily penetrated parts of a floor. There is more likelihood of a leak developing at a drain than anywhere else on a floor, especially if the drain is stopped up. If an expansion joint is placed around a drain, as the joint closes, the sealant is extruded upwards, where it acts as a dam, obstructing the liquids running toward the drain. The result will be a standing puddle at the weakest place on the floor. Therefore, it is best to place the expansion joints at the higher elevations, midway between drains. They should be designed to run crosswise of the direction of fall—not with the slope—so that drainage will flow across them, not along them.

As a rule of thumb, in designing expansion joints, the engineer should make the expansion joint twice as wide as the maximum expansion that he anticipates will take place, that is, the sum of the amount of growth of the brick, and the thermal expansion of the brick in the temperature range for which he is planning. In floors, if the expansion joint is wide, the edges will be pounded by heavy traffic passing over them, and can crumble or spall, causing failure of the joint and requiring frequent repairs. Therefore, the maximum size practical for expansion joints is about $\frac{1}{2}$ in., to accommodate $\frac{1}{4}$ in. of movement. Considering the amount of growth that can take place in the brick available today, that means we are planning for $\frac{1}{4}$ in., which can be reached in about 15 to 20 ft., the latter being the size of the most frequently designed bay in the old buildings. The rule of thumb, then, as previously stated, calls for an expansion joint at least every 15 to 20 ft. of brickwork—more frequently if large thermal changes are anticipated (for instance, in steel pickling tanks operating at over 200°F, spacing is at 7.5 to 8 ft. apart). As stated earlier, they should also be placed between or around all fixed objects except drains.

One of the most frequent errors committed by both designers and contractors in the placing of expansion joints in floors, is the failure to carry the expansion joint through the bed joint (the mortar under the brick) down to the membrane between the brick floor and the substrate. The error most often results from the practice, primarily of tilers but often of brickmasons as well, of troweling the mortar for the bed directly over the membrane, then buttering the edges of the brick, laying it in the mortar troweled on the membrane, and tapping it to tighten the joint and to level the brick face with the other brick already laid. When the location planned for the expansion joint is reached, the side of the brick that will act as the face of the expansion joint is left bare, but the mason or tiler may have already spread the mortar over the membrane and either forgotten it or ignored it. If the mortar is left there, in the bottom of the expansion joint, the brick are locked into a fixed position by the continuous bed under the expansion joint, and the expansion joint cannot function.

The designer should make clear on his drawings that the expansion joint must extend all the way *down to the membrane* (through the bed) and may contain absolutely no hard or rigid material—only the specified expansion joint filler.

THRUST BLOCKS

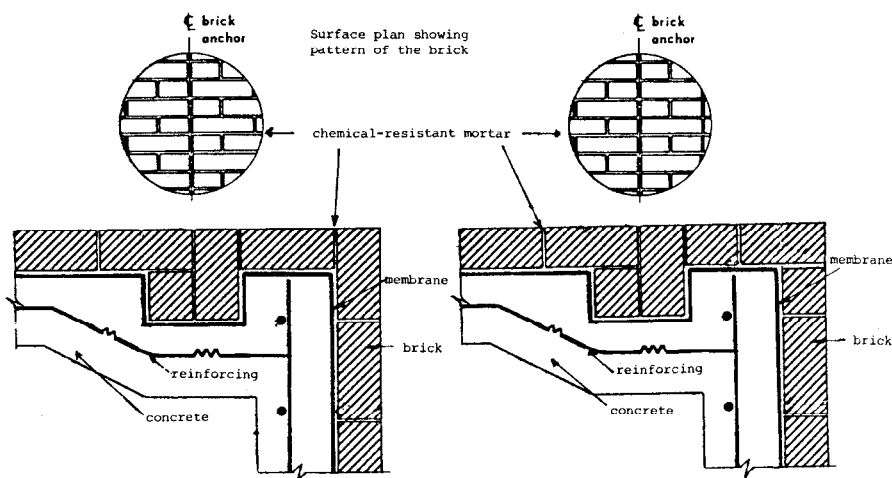
A thrust block may be defined, for our purpose, as a ceramic anchor, set in the substrate to prevent the movement of a brick facing placed over it. It is used to direct the expansion of a brick lining (or surfacing) in one direction only, rather than in both. On a floor, this may be used to prevent damage to the capping and brick lining of a trench or pit when it is undesirable to place an expansion joint adjacent to it.

Let us take as an example a very wet area of floor, draining into a trench, and carrying, perhaps, very small amounts of solvent. Inasmuch as the weakest point in a floor—that most likely to be penetrated—is the expansion joint, it is best not to have an expansion joint close to the trench where all the liquid spillage will flow over it. It should be back at the highest point, or along the wall of the room. Yet normal construction calls for an expansion joint to be parallel to the trench, and back three brick from it. Much less could result in the brick expansion creating sufficient back pressure from the joint to tend to push the brick capping of the trench wall, and the trench wall below it, into the trench. If, however, an anchor is designed into the brickwork along the edge of the trench, the brick can be forced to expand away from it and toward the expansion joint at the high point. Drawing 6 shows how this is done.

Note that the concrete is placed with a slot cast into it, back about three brick from the edge of the trench or pit and running the length of the trench or pit, parallel to it. The pit is wide and deep enough to accommodate two brick standing soldier course—one with the narrowest dimension and one with the width dimension parallel to the trench wall. The depth may be the full length of the brick less the floor thickness, if desired, or it may be less than this, but not less than 3 in. If less than the full length of the brick, obviously the brick will

have to be cut. If the floor is 4 in. thick, it would probably not be worthwhile to expend the labor to cut off 1 in., but if the floor is only $1\frac{3}{8}$ in. thick, it is certainly less expensive than to form a slot the depth of the length of the balance of the brick and adjust the reinforcing accordingly.

The membrane is applied to the floor in the usual manner, carried down into the slot, across the bottom, up the opposite side, then to the trench, down the wall, across the bottom up the opposite side, all in the normal manner, with all corners carefully squared, and properly reinforced throughout. The brick are then laid in the usual manner, except for the soldier course at the slot. The concrete between slot and trench wall is now encapsulated in brickwork, and the cap and wall of the trench are effectively anchored and will not come loose.



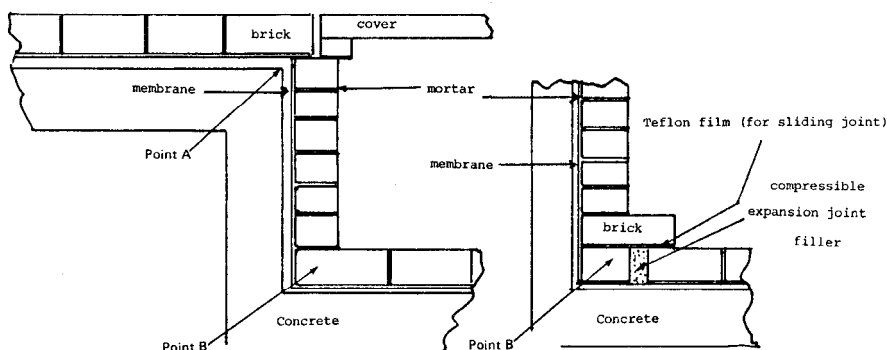
Drawing 6

This leads to another design requirement—that of tying the trench, gutter or sump wall lining to the adjacent floor. Obviously, the membrane must be continuous—passing from the floor, over the trench edge, down the wall, across the bottom, and up the other side. The brick protection also must be continuous. But, in addition, it is important to avoid placing a brick joint at a stress point, if at all possible. See Drawing 6. The left-hand sketch shows the joint between the floor and the cap brick on the trench wall coincides with the back joint of the brick wall—the joint next to the membrane. As you will note, from the possible growth (or expansion) factors in the brick both on the trench wall and on the floor, this joint will be subject to more stress than any of the other joints in the structure. We should, therefore, avoid this design and place brick at this location only in "stretcher" configuration, as shown in the right-hand sketch. The half-brick should be laid next to the thrust block (or if no thrust block, several courses back from the edge).

This same rule regarding cut brick applies to all brick adjacent to expansion joints or any change of direction. The rule is use whole brick in such locations to the maximum extent possible. Under no circumstances, use less than a half

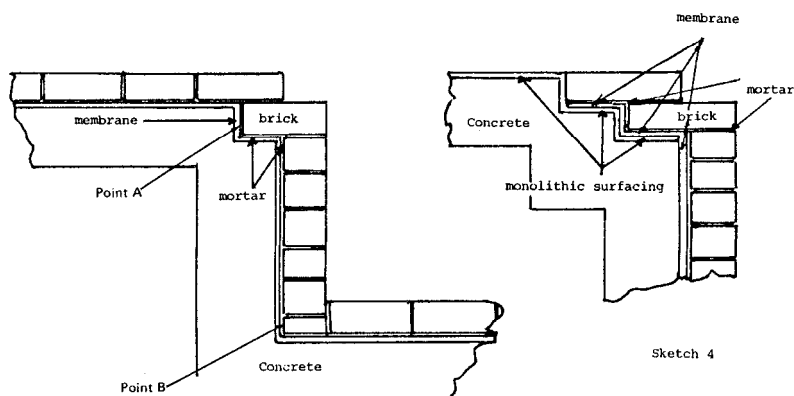
brick. In no case whatever use a "soap" or other brick of less than the full width or thickness in such a location. Set back all cut or part brick one brick or more from the expansion joint or from any change of direction.

Where a removable cover is to be set over a trench or pit, or a steel grating to support traffic, it is important that it does not rest *directly* on the brick lining of the trench. See Drawing 7. Sketch 1 shows a faulty design frequently incorporated into construction drawings. Note that at Point A, we have an even weaker construction than we do on the equivalent part of the unsatisfactory left-hand sketch in Drawing 6. The weight of the grating or cover rests directly on the brick lining. The cover cannot fit tightly if it is to be easily removable for cleaning, and therefore, there will be some play in it, and chattering when wheeled traffic passes over it. The consequences of this are: (1) probable disruption of the joint at Point A, (2) with damage of the membrane behind it and at least some chemical leakage into the substrate at that point, and (3) probably early collapse of one or perhaps both trench walls.



Sketch 1

Sketch 2



Sketch 3

Sketch 4

Drawing 7

To prevent this from happening, a step is designed into the concrete adjacent to the trench wall as shown in Sketch 3. The floor membrane is carried continuously through the steps so there is no interruption in the membrane between floor and trench, and two whole brick are laid: the first in the step, and capping the top of the trench wall, the second carrying the floor over the first to the midpoint of the first or beyond, to the point designed for the cover. Now the weight and vibration of the traffic over the cover is transmitted back into the structure as a *whole* and not directly on the trench lining.

The detail as drawn frequently indicates that the floor will be laid first, then the brick walls erected on the floor. Sketch 1, at Point B, indicates this thinking since the joint between the bottom brick on the wall and the one above it seem to lie in the plane of the top of the floor. This is not the strongest design for a trench (pit or vessel) wall. It is best practice to lay the bottom wall brick first, stretcher course (lying parallel to the wall), then to lay the floor brick inside this. This is the sequence indicated at Point B in Sketch 2.

A moment's reflection will tell the reader why this is stronger. If the bottom joint of the wall is on top of the floor, it is *possible* for this joint to fail and the wall to slide inward or for the joint to crack open and wall to fall in. If, on the other hand, the joints are staggered—by placing either a "split" or a "double" as the bottom brick on the wall and laying the floor inside this, we have removed the joint *from* the fulcrum of the lever.

Please note the detail at the same point in Sketch 2 which shows the method of installing a peripheral expansion joint on the bottom of a trench or pit at the walls. We can, as is usual with compression joints, put foam in this joint. But in a trench or pit bottom rubbish can easily find its way into the joint, immobilizing it. By turning the second brick in the wall header course, so that it extends over the joint and the edge of the floor, and by using a release agent or other sliding joint at this point, the joint is protected, and rubbish cannot enter it to prevent it from functioning as intended.

Where a monolithic rather than a brick floor adjoins the trench, a modification of this design is employed to prevent leakage at the junction of the monolithic and the trench membrane. See Sketch 3. Note the following lining sequence. (1) The monolithic is carried down both steps and to the edge of the trench wall. (2) The hot asphalt membrane is applied up the trench wall (hot asphalt is always carried up from the bottom to the top, never down from the top to the bottom) and across the steps on the top of the monolithic, to the vertical wall of the top step. (3) The brick are laid up the wall, over the membrane to the top, the last brick being placed on the top step. (4) Unless the pit or trench is very small and will involve little or no thermal changes, an expansion joint is placed between the top brick edge and the vertical wall of the last step.

TRENCHES

Open trenches and gutters are the most common devices for handling bulk spillage in work areas. If there is much traffic in the area, trenches require covers. If they are to be kept clean, they must be accessible, preferably in aisles and not under heavy equipment where it will be difficult to remove covers and to get into them to clean them. If they are to drain satisfactorily, trenches must

have reasonably smooth, uniform interior surfaces and a continuous slope with no low spots. In order to conserve working space, the designer usually selects the minimum width combined with the maximum depth he can arrange that will accommodate the fluid volume anticipated.

With those limitations on which to base design, the designer seeks the least expensive construction methods to accomplish the end result. Obviously, if he can use a precast plastic unit, setting it into forms and pouring concrete around it, or a prefabricated stainless steel or other special metal unit, this would be an acceptable space-saving and labor-saving device. The use in such areas, of half-round or "channel pipe," is not recommended. The discussion of such a design in the chapter on waste handling will not be repeated here.

Consider first the special metal design. The coefficient of thermal expansion of concrete is 5.8 to 6.2; that of carbon steel is a little higher. However, the thermal expansion of stainless steel and of most of the chemically-resistant alloys is much higher—for some, nearly double that of concrete. If a prefabricated stainless steel or other alloy trench or pit is bedded tightly in the concrete floor and hot liquids run into it, the alloy will expand more than the concrete. This will result in wrinkling of the structure and quite possibly in damage to the welds. Although such a trench system is installed with some small clearance at the sides into which the metal can expand when hot liquids enter, the real problems will be at the ends and intercepts of the trench since the greatest movement will be in the lengthwise dimension. A small pit may, quite possibly, be lined with an undersize alloy liner set against a foam cushion to accept expansion. Unfortunately, this is not practical with a trench 10 ft. long, and certainly not in a trench with intercepts.

Even if the expansion problems are resolved, there will be great difficulty in applying the membrane in the adjacent floor to make it continuous into the trench. Failure to make the membrane continuous will result in chemical wastes from the floor getting down into the concrete around the metal and under the metal structure, undermining it and damaging the building structure.

Now, let us consider the use of a preformed unit made of a castable plastic. In this case, if the castable plastic is made from a mix designed to a coefficient of thermal expansion similar to that of concrete (and this can be done by the use of suitable fillers), then it can be set in the concrete and mated to the floor membrane system. This can be done by designing a wide flange into the top of the unit, setting the flange directly on the membrane of the floor surrounding the unit, then applying more membrane over the flange and merging the upper layer of membrane into the membrane under the brick floor. Thus the flange is sandwiched into the membrane. This type of preformed trench (or pit) is practical and, if properly designed and cast from low expansion materials, will work.

With this design the brick will end over the membrane on top of the wide flange, in line with the interior of the steel or plastic wall. Provision must be made to keep the brick in the floor from expanding and pushing the brick on top of the flange into the trench. This is done by installing a thrust block two brick lengths away from the trench edge so that all movement will be directed away from that point. (See Drawing 15.)

Thrust blocks are also necessary when two intercepts enter a trench close together, or at opposite sides of the trench a few feet apart. Standard design calls for an expansion joint in the brickwork not closer than 2 ft. or further

than 3 ft. from the intersection to absorb the movement of the brick without developing sufficient back pressure to dislodge the brick on the outside corner. If the intercepts are so close together or at staggered opposite locations so that these guidelines for expansion joints cannot be met, then the brickwork must be immobilized *in that area* with the thrust blocks. Along the feeder trenches, back from the intercepts, however, expansion joints should be located in the usual manner.

Do *not* expect to accomplish the same results with a prefabricated FRP gutter or pit. The coefficient of thermal expansion of such a unit is far too great for such a design to be successful except in very small areas.

Where the trench or pit is large, and/or when mechanical abuse is anticipated (i.e., shovels at clean-out, etc.), the best and longest life protection is still "acid brick." Since, to function properly, trenches must slope so that the depth of the brick lining will vary continuously, it is obvious that it will be necessary to cut brick continuously as the lining proceeds in order to complete the linings of the walls and to mate them with the cap brick and the floor. As an example, see Drawing 4 earlier in this chapter. This is one way of handling the problem although there are about as many other designs as there are brickmasons. But whatever the design, there will be a need to cut brick.

Years ago, it was thought that if the concrete were poured at a uniform depth throughout, the membrane applied, and then the brick walls installed, more concrete could be poured on the bottom, and it could be graded to establish the proper slope. Next, a membrane would be applied over the concrete and side to side bonded to the acid brick walls already installed, then a final course laid on the bottom on top of the membrane and cemented to the brick walls. Obviously, these trenches failed. The membrane on the floor was discontinuous. Acid got into the concrete used to establish the slope, through the acid brick walls, destroying it, and the bottom collapsed.

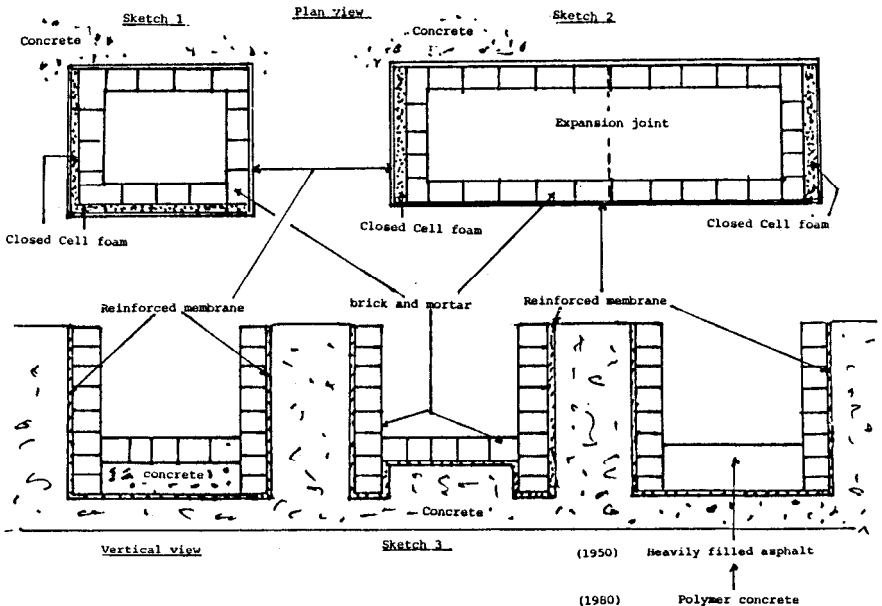
The next method was to form slots for the brick at a uniform depth next to the walls, and a layer of concrete properly sloped in the center. The membrane would then be applied to the entire interior, including the slots. The brick would then be laid for the walls, buttering the brick and pushing them down into the slots. After this, the floor would be laid. When completed, the membrane was continuous. The only problems: (1) the high cost of forming the concrete and (2) the tremendous labor cost in applying the membrane properly in the slots and installing the brick in the slots. This method worked but cost more than cutting the brick. The next idea was to go back to the first design, but instead of establishing the slope with concrete, to use a heavily filled high melting point hot asphalt, similar in appearance to an asphalt road surface, then put the acid brick on top of this. Where temperatures have not been excessive and there was little or no weight on the bottoms, this has worked reasonably well.

A final possibility. Design once again as in the first instance with a uniform, constant depth, place the membrane and lay the walls, then use a polymer concrete castable to establish the slope. If the trench is a long one, the concrete bottom can be stepped at each point where the depth increases by exactly one brick depth. Now, after applying the membrane, the slopes can be established with a polymer concrete without having to worry too much at the material cost of a larger volume of polymer concrete.

Locations of expansion joints in trenches must be planned, not only to accommodate thermal expansion and brick growth, but to protect brick at outside corners from being pushed off the membrane by back pressure from deformable elastomeric material in the expansion joints. In trenches, therefore, in addition to the normal spacing of expansion joints and the placing of expansion joints around fixed objects and over all points of movement and cold seams and control joints in the substrate, at not more than 20 ft. intervals (or evenly spaced apart at lesser distances if the length does not divide evenly into such intervals) they should be placed in both directions at not more than 3 ft. or less than 2 ft. from all changes in direction and intercepts, and before all step changes in depth in trenches.

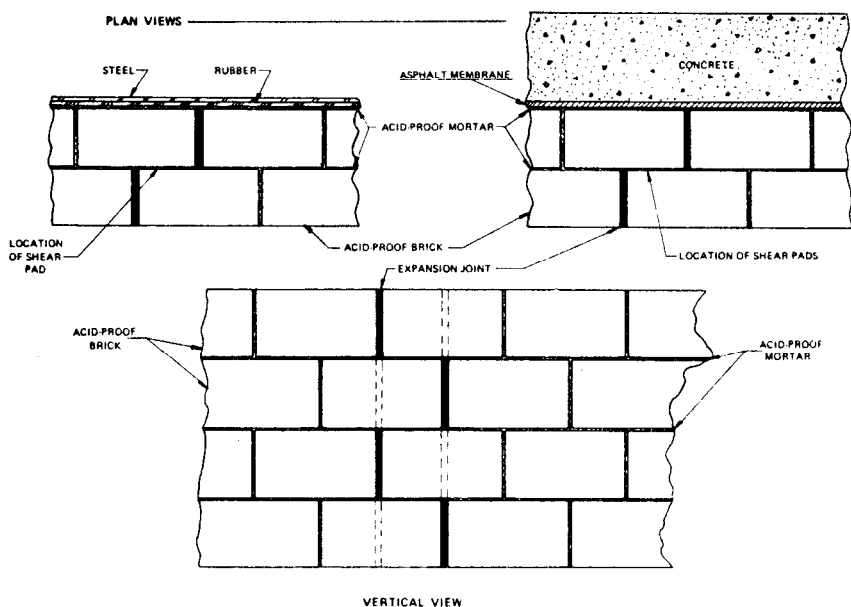
If the trench lining will be exposed to very hot liquids for more than 15 to 20 minutes at a time, or more frequently than once in an hour, it will probably be necessary to place expansion joints at shorter intervals. It should be kept in mind, however, that straight-through expansion joints, such as those we have considered up to now, have very little strength. Of course, any variation from a straight line, such as bulge toward the center of the trench, will practically assure the collapse of the wall, but it will happen soonest at a straight-through expansion joint.

In 20 ft. trenches, with squared ends, it is often possible to eliminate intermediate expansion joints by the use of end pads of closed-cell foam rubber as shown in Drawing 8. This, in effect, "floats" the brick lining between the two foam pads, absorbing its expansion in both directions. The thickness of the two pads must be calculated to accept the maximum movement anticipated in one-half the thickness to be employed in the end pads.



Drawing 8

As the depth of the straight-walled trench or pit increases beyond the ability to line it successfully with 4 in. of brick, and it is necessary to go to two courses, it will be possible to employ the interlocking design expansion joint, which has been in use in steel mills since the 1930s. Drawing 9 shows this design. Note that although there are compression and sliding joints in both courses of brick, the joints are staggered in location so that no two coincide, and the wall retains its strength. Although this drawing shows the expansion joints in both inner and outer courses as winding with the brick contours from course to course, there is an optional way of laying out the expansion joint without excessively weakening the wall by cutting the brick on the face course only, to make the face course expansion joint straight, and only following the brick contours on the back course, so that the rear expansion joint passes back and forth on each side of the joint in the face course.

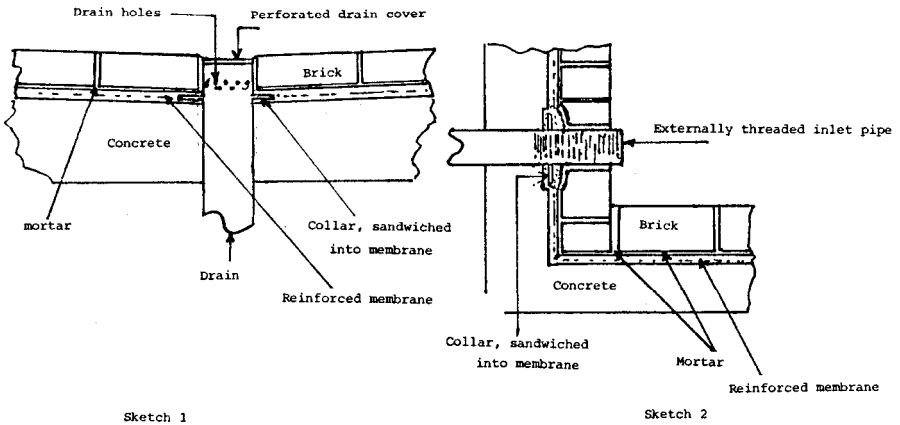


(*Blast Furnace and Steel Plant*, November 1968)

Drawing 9

Penetrations through the trench or pit wall or bottom must be so designed as to prevent penetration or bypass of the membrane. In drains, this is accomplished by the selection of a unit of the Josun type. See Sketch 1 on Drawing 10. Note that this type of drain has a wide collar on the shaft at the surface of the concrete, the thickness of a brick, plus membrane, below the floor level. The membrane is applied over the surface of the floor and under the collar, then an additional thickness of membrane is added over the collar, sandwiching it into the membrane. Above the membrane over the upper face of the collar are weep-holes through the shaft of the drain, so that any liquid that may collect

under the brick and over the membrane will drain through the weep-holes and down the drain, effectively preventing any puddling at the low point.



Drawing 10

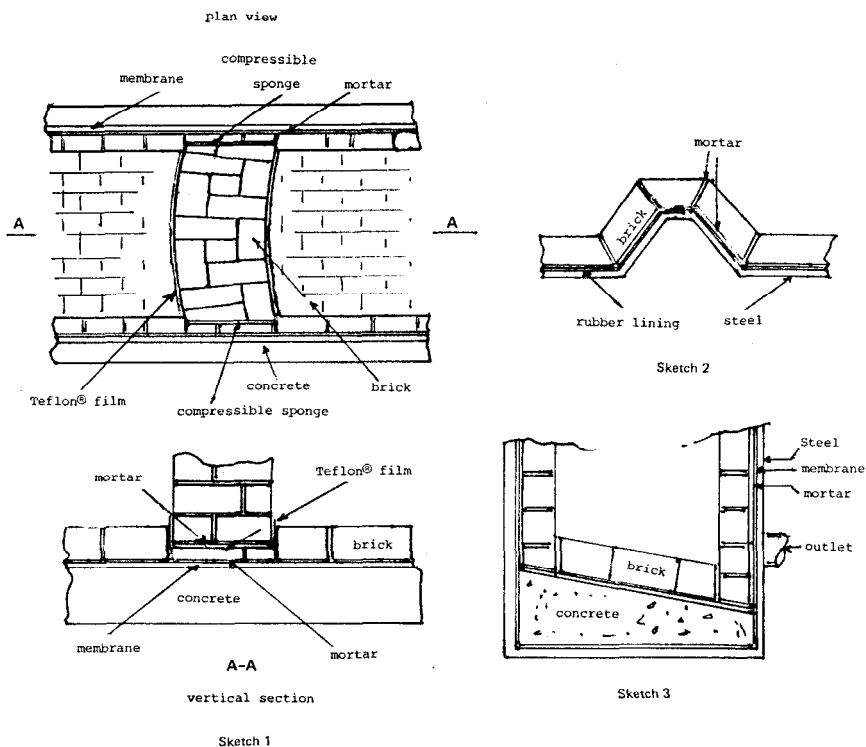
The brick are then laid over the membrane and up to the drain, making sure that all joints, including those between brick and drain body, are completely full and with no voids. The top of the drain should now be $\frac{1}{32}$ to $\frac{1}{8}$ in. below the surface of the brick.

Sketch 2 shows the method of handling pipe entries through the side of the trench (or pit) to drain surface liquids from the area above into the trench (or pit). Note here that a similar type of seal is involved. The pipe extends into the trench $\frac{1}{4}$ in. or more beyond the design thickness of the brick lining. The shaft of the entry pipe is threaded, the threads going back into the wall area, and the concrete recessed a $\frac{1}{4}$ in. minimum at that entry. The hot asphalt membrane is applied, the reinforcing being cut to fit around the pipe up to the pipe shaft, and out along it for almost 1 in. beyond the concrete face. A collar threaded to mate with the threading on the pipe shaft is now screwed down tightly against the membrane in the prepared recess in the wall, and an additional layer of hot asphalt membrane (and fabric) placed over the collar and up to a $\frac{1}{2}$ in. along the shaft. Asphalt must NOT be permitted to get on the rest of the pipe shaft. The shaft should be absolutely clean from $\frac{1}{4}$ in. out from the collar to the end of the pipe. The brick is then laid up to and cemented to the shaft. Heat should be applied to the pipe to warm it until it is just too hot to touch the metal—to 100° to 120°F. This will cause the mortar between it and the brick to flash-cure and bond tightly to the metal. The backs of adjacent brick must be notched to provide for the thickness of membrane and collar, as well as the bed joint.

In placing expansion joints, it must be remembered that drains and pipe entries are both points of no movement, and that they should be centered between expansion joints to prevent the existence of any unbalanced stresses in the lining.

WEIRS AND OVERFLOWS

When the designer wishes to install a weir in a trench, perhaps to allow suspended matter to settle out and be trapped, he should remember that the level (and weight) of the liquid in the trench upstream from the weir will not be balanced by an equal level on the downstream side. Therefore, a straight all-brick wall, built in the normal fashion, will probably have a short life. It is important, therefore, to design it in a curve, with the center upstream from the sides, just as a civil engineer designs a power or water-retention dam on a river. However, unlike a concrete dam, in this case the design must provide for the anticipated growth of the brick. The way this is done is illustrated in the left-hand sketch in Drawing 11.

**Drawing 11**

Note that the wall in this area is built to a thickness greater than that indicated in the guidelines given earlier for pit and trench walls. Since this wall must sustain loading on one side, it is never less than 8 in. thick; at a depth of 6 ft. and deeper, it should be 12 in. thick. These thicknesses are for a wall length (or trench width) of not more than 4 ft. At greater width of trench (and length of wall), a greater thickness will be required. The concrete trench bottom and sides should be recessed in a smooth curve, approximately 2 in.; $\frac{3}{4}$ in. wider than the

anticipated width of the wall. After the membrane has been applied through the trench and the recesses, *and a single thickness of brick $2\frac{1}{4}$ to $2\frac{1}{2}$ in. thick is laid in the recess area*, a strip of Teflon film 3 to 5 mils thick is laid in the recess in the bottom of the trench. The brick wall is then laid in the usual manner in the floor recess, on top of the Teflon film and the brick in the bottom laid up to it on both sides. However, instead of mortaring the floor brick directly to the wall, Teflon film is placed against the bottom side of the wall, in the slot, and up the side of the wall to the top of the floor brick. The floor brick are mortared with a full joint and laid tightly against the Teflon film. As the wall is built, a uniform space, $\frac{1}{4}$ to $\frac{1}{2}$ in., is left between the ends of the wall and the brick in the wall slot, and this space is filled with a closed-cell foam (or other compressible joint filler) selected for the anticipated service. The trench wall brick is next laid up against the partition wall brick, once again imposing a Teflon film between the mortared trench wall brick and the sides of the divider wall.

Now, as the weir wall brick grow and expand, the brick can release thermal stress by sliding outward on the Teflon film under them, and slide into the brick slots in the wall, compressing the foam. This curved design provides for both the thrust against the wall from upstream and the expansion of the brick in the weir wall. The designer should bear in mind that like other all-brick structures, this wall will not be liquid-tight and will weep into the downstream side. It will, however, act to trap any suspended material that settles out.

An all-brick divider wall should never be used to make two chambers out of a single concrete structure. If the two chambers are filled to much different depths, the wall is sure to fall down toward the low level side. In addition, the wall can never be made liquid-tight. There will always be leakage from one side of the wall to the other. There should always be a concrete divider wall installed in such a vessel, the membrane made continuous throughout each cavity, and the brick lining installed over it in the same thickness and design as in the rest of the vessel.

When a weir or overflow is to be installed over such a divider wall, the section of the overflow should be designed as a slot in the concrete wall, and the membrane carried through the slot, sides and bottom, and sealed continuously to the membrane in the adjoining vessel. Then the brick is laid through the slot, protecting both sides and bottom and tightly bonded with the brickwork on both sides. Remember that this is a fixed point—an area of no acceptable movement—so it should be centered between expansion joints. If the vessel is a deep one, it may require a circumferential expansion joint around the inside of each vessel to prevent vertical growth from pushing the bricks off of the bottom of the slot and disrupting the brick on the sides of the slot.

VESSELS

This naturally leads into a consideration of vessel design. The importance of contouring and of expansion joints has been covered earlier; other design details common to vessels and trenches have been touched on in Drawings 1, 3, 4, 5 (for sloping bottoms), 6 (where there may be a need to control the direction of

expansion movement), 7 (if a removable cover is required), 8 and 9 for the expansion joints themselves, and 10 for entry pipe for concrete vessels—preferably above the normal liquid level.

Divider walls in concrete tanks have just been discussed. It is appropriate here to mention an additional limitation of this kind of a design. At the beginning of this study, it was said that a major use of chemically-resistant masonry is to provide thermal insulation to the membrane. If this is hot asphalt, and in nine out of ten concrete tanks it is, then the top service temperature acceptable is 135°F. It is possible to operate a concrete tank lined with hot asphalt at boiling (212°F) if the asphalt is inner-lined with an adequate thickness of acid brick to bring down the surface temperature of the asphalt to the acceptable range. However, if a common divider wall or a brick-covered baffle wall is put in the tank, the wall (or concrete baffle) will be heated from both sides, so that the full thickness will eventually reach the same temperature as the interior, and there will be no cooling effect. The asphalt temperature will rise to the temperature of the contained liquid, and it will flow, squeezing upwards and out under fluid pressure, causing the failure of the tank. Therefore, with a common wall in a concrete tank, the internal temperature of *both sides* of the wall should never exceed 135°F. This rule does not hold true for steel tanks because it is possible to design a divider wall in a steel tank with a ventilation arrangement. See Drawing 11, Sketch 2.

The design indicated in this sketch has been a successful standard in steel mills for well over 40 years for use in 300 ft. and longer steel strip pickling tanks of five or more compartments, operating at close to the boiling temperature and lined with rubber sheet, top limit surface temperature, 160°F. Two or more courses of acid brick are laid over the rubber, and steel strip is pulled at a uniform speed through the cavities from one end to the other, over the common walls, passing from strong, hot acid at the start, to hot water rinse at the end.

BOTTOMS

Above, with Drawing 5, various methods of attaining slope in the bottom of concrete trenches were discussed. Unfortunately, there is a school of thought that applies a similar approach to the design of tanks with sloped bottoms. The theory is that it is more costly to fabricate a steel tank with a flat bottom sloped to one side than to fabricate the vessel with a dead flat bottom and attain the slop with a false bottom, because a sloped fabricated bottom would require the bottom stiffeners and supports to be designed in different lengths to provide rigid support and to keep the sides vertical. By fabricating the steel as a right cylinder, or a true rectangular box, the bottom dead flat, all supports and stiffeners can be uniform in size and thickness. The desired slope is then attained by pouring an additional bottom of concrete into the vessel and sloping the concrete to the desired low point, finishing the concrete to a true, smooth plane. After the concrete has cured, the membrane, whatever the type, is applied to the steel walls and continuously across the concrete and up the opposite side. (See Drawing 11.)

Sometimes, when the design calls for a sheet rubber lining, the steel vessel

is lined completely with the sheet rubber before the concrete is installed. Then after the concrete has cured, an additional membrane is placed over the concrete and sealed (continuously it is hoped) to the rubber sheet already applied to the steel walls, encapsulating the triangular section of concrete in the bottom.

The engineers who favor this design fail to take into account several important factors. (1) The application of the membrane system over the concrete surface, and its *continuous* sealing to the wall membrane is a more difficult operation than the continuous lining of a steel tank with its bottom properly fabricated to the required slope. It is impossible to *verify* the liquid tightness of the seal between the wall membrane and that last applied over the floor. In other words, there is no test available to prove that this joint will not leak and permit chemicals from getting down into the concrete fill. (2) The coefficient of expansion of carbon steel is about 5 to 10% higher than that of concrete. It will also heat and expand a little faster than concrete. Thus the *sides* (which are steel) will heat up a little faster than the bottom and try to move away from the concrete fill. This will result in stretching the material used at the seal. If there are any weak points in the joint, they may be ruptured, and if any holidays, they may be enlarged. (3) With the *bottom* of the tank thicker than the walls by the thickness of the concrete fill, the bottom will absorb heat, not radiating it as fast as the walls, and the membrane at the bottom will be hotter than on the walls. This is important only if the vessel is operating at a temperature near the upper limit of the membrane.

Whether to line the steel completely *before* putting in the concrete or to wait until the bottom concrete is installed is arguable. One school of thought points out that if acid gets into the concrete through the failure of the membrane on top, if there is a complete lining *on the steel*, the acid cannot reach the steel and "hole" it. The thinking of the second school is that if acid gets into the concrete and damages it (but is held in the tank by a membrane below it), it will result in the deflection of the brick lining over the membrane—and the loss of both membrane and brick, and subsequently of the vessel, before the operator is aware that he has a problem. On the other hand, if there is no membrane over the steel below the concrete, the bottom will hole and start to leak in time to warn the operator to shut down and repair before the vessel is lost. A better way is to (1) preline all the steel with the appropriate membrane, then (2) place the wall brick, and (3) cast the slope into the bottom using a polymer cement such as a furan, vinyl ester, or epoxy, as may be suited to the chemistry. If it is always on the acid side, and no fluorides are present, a silicate castable may sometimes be used. If this is done, it may be possible to avoid having to use brick in the bottom. Of course, the thermal problem mentioned above will still be present.

Regardless of which reasoning is preferred, obviously the best answer is to have the tank fabricated with the bottom already sloped, and to avoid the use of two totally dissimilar materials joined together.

From the standpoint of long life and freedom from maintenance, dished, hemispherical and cone bottoms are the best for cylindrical tanks, and are the designs of necessity if a vessel is to be "prestressed" (see Chapter 47), or if there is a desire or necessity to eliminate expansion joints. Flat bottoms, unless provided with properly designed expansion joints, will heave upward with brick growth. In addition, adequate and frequent stiffening is required if flexing and

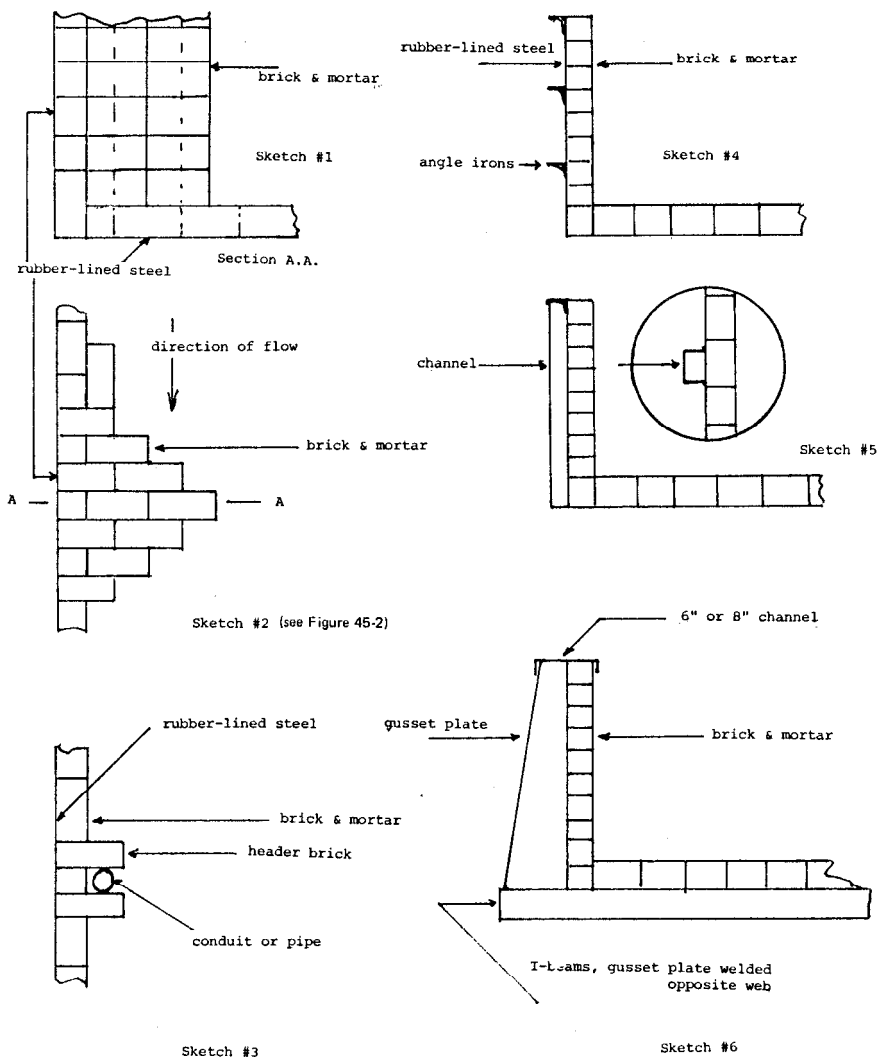
"oil canning," which can damage brickwork are to be avoided. Flat bottoms, however, are the cheapest to fabricate and, therefore, are the most frequently designed—especially by those engineers who have not fully analyzed their disadvantages.

A favorite method of support for flat bottom tanks—to avoid using the I-beams that should be welded at frequent intervals across the bottom—is to pour a good smooth flat concrete foundation, cover it with a $\frac{1}{4}$ in. thick layer of soft asphalt or tar, and set the tank on it, allowing the tank's weight to squeeze asphalt out on all sides. If the vessel is to be used only for ambient storage, this will be acceptable. But if the temperature of the tank's contents is much more than 10°F higher than that of the surrounding air, the designs may experience trouble. The sides of the tank are in contact with the air, and will cool off, keeping the wall temperature down. The bottom, however, is in direct contact with the support pad and its asphalt cover, and cannot radiate the heat. It becomes a heat sink, and will slowly heat up until it and the contact surface below it, have reached the same temperature as the contents. Now, at more than 10° hotter than the walls, the steel bottom will expand. It is restrained, however, around its entire periphery by the hoop of the steel walls, which are 10°F or more cooler so it cannot press outward. It cannot flex downward because it is continuously in contact with the pad. Therefore it flexes upward at the center to relieve the expansion stresses, and in doing so cracks the brick, exposing the membrane. If the interior is operating at a temperature above the maximum service temperature of the lining, the membrane on the bottom will already be overheated. The destruction of the bottom brick lining makes the problem worse, and the membrane will eventually hole—probably near the center of the tank. Chemicals now leak under the tank. Sooner or later, they get through the asphalt and into the concrete—usually about the center of the pad. Before the operators realize that it is leaking, it will have weakened and probably seriously damaged the bottom of the tank, and the support pad will most likely be beyond repair. There will be no way of rehabilitating the tank, and it will have to be scrapped and replaced.

As noted earlier, when a common wall divides a single concrete vessel into two, that wall is heated from both sides. The structural support of the wall and the membrane protecting it will come up to the same temperature as that of the contained liquids, while the outer walls, which can dissipate heat to the surrounding air, will be considerably cooler. (The mathematical formula used to compute the temperature of the surface of the membrane is given in the chapter on prestressing, and so will not be repeated here.) Therefore, if a common wall is to be included in the design, the membrane must be selected to accept the full temperature of the contained liquids. If there is no membrane that can handle the contained liquids at this temperature, this design must be abandoned. If this design is used, and expansion joints cannot be used in the brickwork, due either to temperature or contents, the divider wall must be contoured.

For the same reason, care must be taken in the design of any baffle walls that may intrude into the vessel. If the baffle will only extend a short distance into the vessel, it may be constructed of masonry, with the brick so laid as to interlock it into the wall brick lining. With no membrane, the heat sink problem ceases to be a limitation. Where the baffle extends much more than a foot into

the vessel and agitation is planned, structural support (steel in the case of a steel vessel or concrete in a concrete vessel) is usually required. In this case membrane protection is needed, and the membrane must accept the temperature of the contained liquid. See Drawing 12 and Drawing 14 for suggested details of baffle design. If the baffle is a long one, the structural support should also be contoured and be dumb-bell shaped (with a rectangular head) so as to keep the brick on the shaft in compression. (See also Figure 45-2.)



Drawing 12

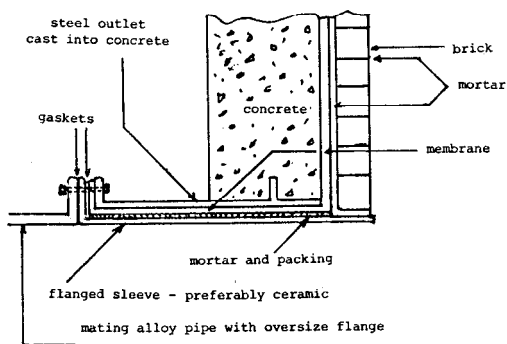
Earlier in this chapter there was mention of the importance of ventilation under the tank if the vessel is a heated one (to eliminate a heat sink effect), and the methods of supporting a flat-bottomed steel tank on I-beams at frequent intervals to permit this ventilation. In addition, it is important for the walls to be rigid so that they will support without distortion the masonry lining of a rectangular vessel. There are several ways of accomplishing this. Angle irons continuously welded around the top and waist of the walls are frequently used as an inexpensive way to provide stiffness. However, spillage over the top, or drips from work carried out of the tank can be puddled on such girth angles or migrate to the welds, and "hole" the tank or damage the weld at that point. The use of a channel at the top, so that drips fall free of the tank wall, rather than following under the angle and down the tank side is an improvement. Best of all are gusset plates welded vertically against the walls, under the channel at the top, and to the I-beam supports under the tank, with the I's extended to meet the base of the gusset plates. The gussets must be welded to the center of the I opposite the web, and not to the edge of the I. (See Drawing 12.)

Occasionally vertical support stiffeners have been designed and specified as channels, placed with the flat body away from the tank wall and both of the ends welded to the steel wall plate. This design encapsulates a column of air against the outside of the tank wall. Aside from the insulating effect on the wall, preventing this area from cooling as much as the area around it, with consequent local overheating of the membrane in this area, and the stresses in the steel caused by differential expansion, there is a column of air that may be or become contaminated with corrosives held against the outside of the tank wall, an enclosed area that cannot be reached to be serviced. This is *not* good design.

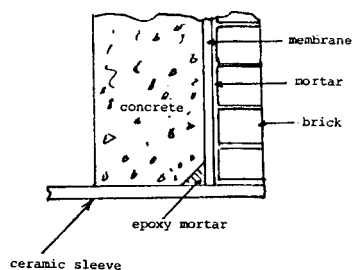
Concrete tanks, properly designed and reinforced, need no stiffeners either on walls or bottoms. However, if the bottoms are not to be "heat sinks" and require a high temperature membrane, provision must be made for ventilation under them, such as designing the tank to stand off the floor on a series of piers, or have supports with air spaces between them.

Obviously, cylindrical vessels require no vertical external stiffeners, as their contour provides the necessary rigidity. But they still, of course, require bottom support.

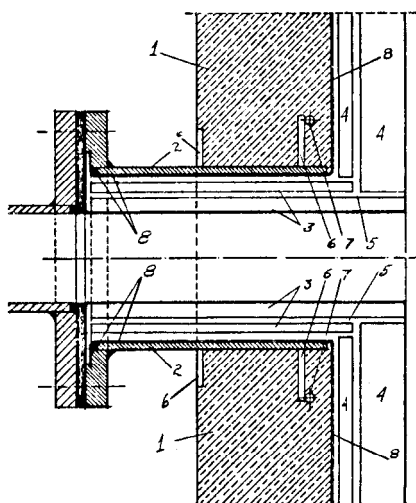
Outlets and inlets—penetrations through walls and bottoms—are the most frequent sources of trouble—and failure—in vessels. It is, therefore, preferable, to load and unload vessels over the top of a side, and to have no outlets or inlets. It is especially important to avoid unnecessary penetrations such as thermal wells and heater or agitator entries. Also, heat exchangers and the like may be served over the top of a side rather than through it. This way, it is unnecessary to spend the extra funds on membrane lining and thermal sleeving on inlet nozzle. (See the nozzle details in Drawing 13, and those in the manhole details in Chapter 46 on waste handling.) It is necessary, however, to protect the pipe or conduit leading to a heater, thermocouple, steam jet or other instrument, from bumping, from abrasion or from other mechanical damage by the contents of the tank or by equipment. This may be done by setting headers into the brick lining to provide a pocket in which the piping or conduit can lie. (See Sketch 3 in Drawing 12.)



Sketch #1



Sketch #2



Sketch #3

European practice for outlets in concrete tanks with non-asphaltic fluid-applied membranes.

- | | |
|---------------------|---|
| 1 = concrete | 5 = acid-proof mortar |
| 2 = steel | 6 = steel skirt welded to nipple |
| 3 = ceramic sleeves | 7 = reinforcing steel, set in the concrete, welded to skirt |
| 4 = brick | 8 = fluid-applied membrane |

("Blast Furnace and Steel Plant", November 1968)

Drawing 13

Membranes should be continued out through all nozzles (inlets and outlets) and over the exterior flange, so that the membrane has no discontinuity.

Failure to do this will eventually lead to failure. Some membrane systems of differing types that may be lapped and the lap pressure-sealed are occasionally used in a compromise design. (See the manhole outlet designs in Chapter 46, and the details in Drawing 13.) The detail in Sketch 2 is not as safe and foolproof as that in Sketch 1, but in exposures that are not subject to a continuous *liquid head*, it may have an economical life expectancy.

CAPPING

In designing concrete tanks, it is common practice to carry the reinforced asphalt membrane up the walls and over the tops of the concrete, and to continue the brick lining in the same manner—over the top of the wall. Often the membrane is carried down the outside of the tank, the outside is veneered with brick as well, and the membrane and brick continued onto the surrounding floor. If such a system is properly designed and constructed, the life expectancy of the system will be a long one. This is a closed system, with no discontinuities in membrane, and except for mechanical injury there is no way corrosives can enter the building structure.

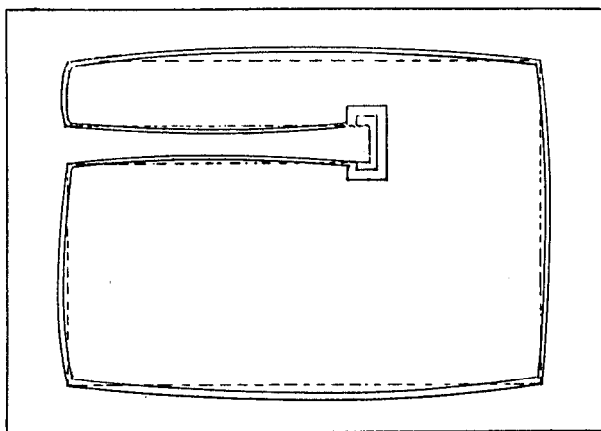
However, there is a problem in such design that must be provided for. The interior temperature of the tank will almost certainly be higher than the exterior temperature. The brick capping has two horizontal outside corners—the one at the top of the interior wall which will be hot, and the one at the top of the exterior veneer, which will be at ambient temperature. Therefore, the interior portion of the cap will expand due to the thermal difference, and shear cracks will develop in the capping, parallel to the side walls unless a *sliding* expansion joint is provided in the cap to permit this differential movement. (See Drawing 14.) The interior vertical expansion joints in the walls are continued up to this sliding joint to permit the interior expansion joints to close and open as the tank is heated up or cooled down, while the cap brick over the top of the wall moves with the brick in the wall. The balance of the capping remains in place closing up into the provided compression joints for the cap which are only required to handle brick growth.

If there is no veneer on the outside—only the brick cap—then the sliding joint should be placed between the cap brick and the top of the wall brick parallel with the membrane on the top of the wall.

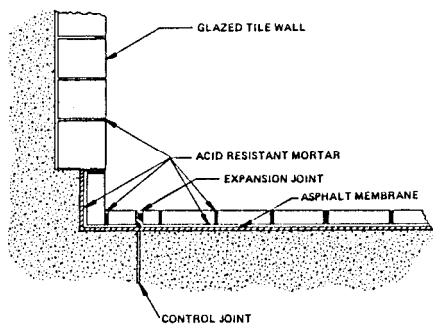
If the tank is steel rather than concrete, a rigid capping such as brick is not recommended. The membrane system, such as a rubber lining, is carried up the walls, over the channel (or angle) at the top and down and under the channel before terminating. A timber bumper, the same width and length as the walls, not less than 1 in. thick, preferably 2 in. with corners mitered, is placed over the top of the channel and bolted down tightly to it using alloy bolts and nuts, passing through the timber and through rubber-lined holes in the channel. (See Figure 5-5, page 82). It is recommended that the head of the bolt be counter-sunk into the wood, and covered with resin mortar to limit the chemical penetration along the shaft.

COVERS

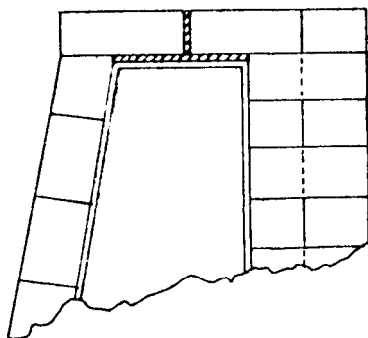
Brick cannot, of course, be used to line the underside of a flat cover. If the cover is fixed in place, and is a dome, then it can be brick-lined. What, then, can be done to provide insulation protection for the underside of a flat cover? From at least the first decade of the 20th century to 1975, no insulation over the membrane could be provided. The following procedure has been used for concrete tanks.



Typical rectangular concrete vessel design with bowed walls to keep brick lining "in arch". Note design of baffle wall extending into vessel, sides contoured and hammerhead design to keep brick lining in compression.



Floor juncture with glazed block wall.



Interlocking expansion joint in vessel lining ends at rubber inverted "T" (T) at brick cap. Shaft of rubber "T" shear pad permits lateral movement at this point independent of brick veneer on outside of vessel. Cross bar of "T" is set flat on membrane covering top of tank wall, and brick are laid up to and against the shaft on both sides.

See "Chemically Resistant Masonry", W. L. Sheppard, Jr. (1981)

Drawing 14

The concrete vessel—whether rectangular or circular—has been completed, lined completely with a hot asphalt membrane and acid brick. If the vessel is large, an all-brick column or support for the cover may also be constructed in-

side the vessel, to the same height as the top of the walls. A collapsible flat form is then built up in the cavity between the sides and/or next to the column, with the top of the form flush with the top of the sides and of the column top. Flat rib-back clay liner plates (ASTM C-479) are laid flat, face down on the top of the form, as if one is laying floor brick, and the edges mortared with the same mortar used to lay the brick in the vessel. From the edges of the form to the outside of the walls (and over the column, if there is one), the liner plates are laid *and mortared* to the brick masonry. After the joints have cured, the joint surfaces are coated with a layer of $\frac{1}{4}$ in. thick hot asphalt. Finally, over the liner plates concrete is poured, reinforced with steel reinforcing. When all this is cured, the manway of the tank is entered, the form collapsed and removed, and the tank is ready for use.

As the reader will realize, this procedure will not be very satisfactory for a cover for a steel tank. If it is a fixed dome or conical cover, it may be lined with brick, but if the cover is to be removable, the cover may be steel, employing a high temperature membrane, or a precast polymer concrete or prefabricated FRP construction.

The liner plate lining of the underside of a concrete cover does not offer permanent protection. For one thing, there is no membrane between the liner plates and the concrete—only the layer of hot asphalt over the mortar joints. The liner plates are not as dense as, have a higher absorption than, acid brick—6% allowable—and they are thinner than acid brick. The absorption testing of liner plates is accomplished under ASTM C-301—by no means as stringent a test as that used for acid brick. Consequently, the economical life of this kind of a cover is limited. In vessels handling ambient temperature wastes, the cover may last a number of years. But if the vessel operates at an elevated temperature and contains a volatile corrosive such as hydrochloric acid, tile may start falling off in less than a year. In the past the only alternative was the same kind of covers used for steel tanks.

In the early 1970s, light, closed-cell foamed borosilicate glass block (see Chapter 17) were developed. These block, with a mass of only 12 lb/cu.ft., will adhere to the underside of a concrete or steel cover by using a urethane asphaltic adhesive; all joints between them are made the same way. Insulation of this type has been applied to the underside of both concrete and steel covers and has functioned successfully for a decade.

PRESTRESSING

Prestressing is a process employed in design to make sure that under anticipated operating conditions, the steel outer shell of a vessel does not expand away from a brick or other masonry lining, leaving the lining without support and in tension. Designs of this type are used where there may be insulation on the outside of a vessel, or there is to be a thin lining—too thin to provide sufficient internal insulation to keep the skin temperature low enough so that the steel will not expand faster than the brick.

This procedure finds primary use in the dye manufacturing industry, but is also used occasionally elsewhere in other chemical processes. It is done by em-

playing a mortar for the masonry units that follows two different setting cycles. The brick (or other block) are laid up using *wide* joints at ambient temperature inside the vessel, and the mortar goes through its primary cure and becomes hard to the touch. However, it retains a certain amount of elasticity. The vessel is then filled with a neutral solution such as sodium chloride, and slowly heated internally until the internal temperature has reached the anticipated operating temperature. During this slow heat-up, the shell warms and expands, and reaches the temperature and expanded dimensions that it will attain under the service conditions. As it expands, the weight of the contained liquid presses the brick lining outward, keeping it in contact with the supporting shell; the mortar joints stretching to permit the movement.

The vessel is held at or above, the operating temperature for 48 hours, during which period the mortar undergoes its secondary "cure"—hardening totally in its "stretch" condition. After 48 hours when the heat is removed and the tank cools down, the steel tries to shrink back to its original dimensions but cannot do so because the brickwork is now solid and immovable. From then on the vessel can be cycled through this thermal range without damage to the vessel or the masonry lining.

In order to design for prestressing, computations must be made carefully to determine what stresses will be built into the vessel, and what amount of "stretch" will be required in the mortar joints. This is discussed in Chapter 47. From the data computed, the designer will determine the required parameters for this vessel design. He must then refer back to the mortar supplier for the "quellung" factor, or amount of stretch that the semicured mortar selected for the lining will accept without joint fracture. From this factor and the amount of expansion that the lining must accommodate, the number and size of the joints are determined. The installer must be very careful in laying the brick, to use spacers in the joints to be sure that they do not close up or tighten under the weight of the lining, and so make the joints smaller than designed. Failure to follow *exact* design and joint size will result in failure of the lining.

EXPANSION JOINTS IN VESSELS

Design and location of expansion joints in vessels follow the same rules as those in floors and trenches. The designer must remember, however, that there is less opportunity for the lining to cool where liquids are contained (held) than when they are transient and, therefore, the maximum movements must be designed for. As in trenches, inlets and outlets are fixed points and, therefore, should be centered between expansion joints. Therefore, in a tall vessel with inlet pipes penetrating the walls near the top, circumferential expansion joints are indicated. If there are no inlets and no capping or cover, the designer may decide to allow the lining simply to expand—sliding up the walls. If there is an inlet, however, the lining of the inlet will be sheared off. If the tank is not deep and the expansion will be minor, he may opt for lining the inlet with a flexible liner so that it can accept such movement without damage. Teflon sleeves have been employed for this purpose.

MORE ABOUT FLOORS

Back on the subject of floors, there are a number of matters that must be discussed:

- (1) Monolithic surfacing.
- (2) The difference between expansion joint design and location in floors protected with bonded tile or brick, and monolithic toppings and surfacings, and in floors protected by "acid brick" laid with chemically-resistant mortars over an impervious membrane.
- (3) How to determine the appropriate thickness of a brick floor over a membrane.
- (4) Curb design.
- (5) Walls subject to spray or splash of corrosives, adjacent to acid-resistant floors.

Monolithics

To this point, the discussion has centered on "acid brick" and similar "unit construction." Monolithics require quite different design criteria. Monolithics may be subdivided into three types:

- (1) Toppings and surfacings applied to the surface to be protected (usually concrete, occasionally steel, and very rarely, wood) in thicknesses usually of $\frac{1}{8}$ to $\frac{1}{4}$ in., although very occasionally as much as $\frac{1}{2}$ in. or slightly more, most often by troweling.
- (2) Grouts and polymer concretes, placed most often by pouring or casting, in depths of 1 to 4 in., sometimes more, and often used to repair or fill deep holes in a substrate.
- (3) Gunned linings, which are covered in other sections of this book.

The first two types are materials that shrink after placement as they cure and harden. The usefulness of these will be limited by their ability to maintain their integrity—a continuous, undamaged, fracture-free structure—and to provide adequate resistance to the diffusion through them of the corrosives to which they will be exposed. In addition, in the great majority of cases, these materials will have different coefficients of thermal expansion than does the substrate to which they will be applied.

The principal difference between the two types is that monolithics, if they are to survive, must be tightly bonded to the substrate, relying on the rigidity of the substrate and that bond for their integrity, so that there may not be a liquid-tight membrane placed between the substrate and the monolithic. A polymer concrete or grout, on the other hand, because it is used in adequate thickness to provide good physical strength and to be self-supporting, may be separated from the substrate by a membrane which will continue to protect the substrate if the polymer or grout should crack.

It should be noted at this point that concrete designers have developed

many different and varied additives to include in concrete formulations to affect cure speed, water content, strengths, density, etc. Rarely, if ever, do they consider the chemistry of a surfacing material which the designer may plan to place over the concrete and bond to it. A number of these additives have been found to react with a component of the surfacing material and impair its cure or the bond to the concrete surface. Care must, therefore, be taken in mixing and placing the concrete that absolutely nothing other than portland cement, sand and aggregate that has been approved by the manufacturer of the monolithic be included in the concrete mix.

In the materials section of this book, there is a general summary of the cure shrinkage and expansion characteristics for toppings and for polymer concretes of the various types used at this date in chemical service, together with the kinds of corrosives and the thermal ranges they can accept. Where continuously wet conditions and/or a standing head are anticipated, the possibility of diffusion through a monolithic surfacing should be kept in mind. Under such conditions, a membrane should probably be included in the design—eliminating the possibility of using a monolithic surfacing.

It is not usual to use reinforcing in polymer concrete, although if reinforcing material suitable for the specific environment is available, there is no reason why it should not be used if desired. Most polymer mortars are, however, sufficiently strong so that reinforcing is not necessary. Monolithic applications, on the other hand, are frequently reinforced with glass or other ceramic fabric, or a carbon or a synthetic fiber if the exposure will include acid fluorides. Opinions are approximately evenly divided as to the desirability of such reinforcing. The least cure shrinkage is experienced when the resin content is the lowest and the amount of filler is greatest. Fabric, however, is hard to wet with resin, and in order to wet it out and get good bond to the fabric reinforcing, more resin and less filler must be used. Therefore, in such formulations the cure shrinkage will be greater.

The fabric imparts strength to the structure and distributes the stresses as the material cures adhered to the substrate, but there will be more shrinkage stresses in this structure than there would be if less resin and more filler were used. By distributing the stresses, there is less tendency to crack in the thinner sections. Many designers who do not regularly recommend fabric reinforcing, will make an exception of locations where there are changes of direction, and suggest reinforcing be done in such areas, extending 2 to 4 in. on each side of the direction change.

When a monolithic surfacing is applied to a concrete substrate, in most cases much of the cure shrinkage of the concrete has already taken place. However, the concrete contractor will have, perhaps, installed expansion joints in the slab, and should have cut in or formed control joints as well, so that any future shrinkage will occur at these intentionally weakened parts of the slab rather than in random locations. In addition, there will be "cold seams"—locations where a concrete pour was completed one afternoon and another pour made a day or so later, or fresh concrete was poured against dry, partly cured concrete. This joint is also weak, and with shrinkage of concrete over the years will probably also crack.

When monolithics are applied to this slab, if they bridge these points of movement, or bridge a working crack in an old concrete slab, such movement in the substrate can be expected to crack the monolithic directly over it. In other

words, the crack in the substrate will telegraph through the topping. For this reason, it is vital that if the floor is to function as it was designed to, expansion joints be placed in the monolithic surfacing directly over these points, filled with the correct selection of expansion joint sealant for the anticipated exposure, so that the surfacing on each side of the crack can move with the substrate without damaging the topping and still prevent liquids from entering this crack and undermining the topping.

These expansion joints isolate sections of concrete and topping from each other. If these sections are large, however, they may not provide for all the stresses in the structure. As topping materials cure and shrink, internal stresses will accumulate over the full uninterrupted distance of the topping, while the topping is kept from pulling its surface together by the bond between the topping and the concrete. Experience has shown that where the cure shrinkage of a monolithic is in the vicinity of 0.05 to 0.1%, and that monolithic is applied to a dead flat surface *more* than 20 ft. long without an expansion joint or other interruption in its 20 ft. length, these accumulated stresses can exceed the strength of the adhesive bond to the substrate at the thinnest section, or the area of the concrete substrate that is the weakest, or a portion of the topping that was not uniformly mixed or has a little less curing agent in it than another, or any of a number of other characteristics, that would make that area a little weaker than the surrounding ones. When this happens, disbonding occurs, and at that point the stresses now concentrate as tensile stresses, and cause the cracking and eventual break-up of the topping.

Where this 20 ft. linear distance is exceeded, therefore, it is wise to install "stress relief joints." These are, quite simply, cuts through the topping to the surface of the slab filled with elastomeric expansion joint sealer. The stress lines in the topping cut in this manner prevent the accumulation of sufficient stresses to exceed the strength of the bond of the topping to the substrate. If there are expansion joints at 15 to 20 ft. intervals, obviously there is no need for such stress relief joints. But if the expansion joints are at 30 ft. intervals, then a stress relief joint of this kind should be placed at the midpoint of this 30 ft. span to prevent such stress buildup.

If quarry or ceramic tile is adhered to the concrete substrate with a strong adhesive, exactly the same rules as for the monolithic should be followed, including stress relief, since the adhesive functions in an identical manner. The tile must be cut to place the expansion joint in the tile exactly over the one in the substrate. On the other hand, if the floor is protected by "acid brick" laid on a membrane, the membrane acts as a "sliding joint" as described earlier, and the expansion joint in the brickwork may be offset by as much as a brick length from the point of movement in the substrate—saving the installer the cost of cutting brick to match exactly the expansion joint in the slab.

Where cure shrinkage is expected to be greater than 0.05 to 0.1%, more frequent and larger expansion joints should be planned, with distances between joints reduced proportionately.

Experience also indicates that the optimum size for expansion joints is $\frac{1}{2}$ in. across. At this dimension, wheeled traffic (with 6 in. or greater wheel diameter) over the joint—if the joint is filled with a reasonably hard sealer such as a flexibilized epoxy, but with an elongation of 50%—can be accepted without damaging the sides of the joint.

Elsewhere in this section, we have discussed the irreversible growth of acid brick, usually considered to be about 0.16% of any dimension (about $\frac{3}{8}$ in. in 20 ft. of 8 in. brick). Some brick, especially underfired ones, may grow more than this. From design experience with the brick of the particular manufacturer the contractor plans to use, the engineer should compute the frequency and width of expansion joints in any brick floor that he plans, to be certain that there is adequate provision for such movement so that "heaving" of the floor as a result of brick growth and thermal changes will be avoided.

Differences Between Expansion Joints in Bonded Brick and Brick over a Membrane

The first choice, all things being equal, in selecting protection for a floor is "acid brick" and mortar laid over a suitable liquid-tight membrane. The membrane most often is hot asphalt, although, depending on conditions, another type may be chosen. The membrane system provides a sliding plane so that as brick grow irreversibly, or expand and contract under thermal changes, the floor area can relieve the stresses in the brickwork by sliding toward suitably placed expansion joints causing the joints to close up under growth and thermal expansion, or open somewhat as temperatures drop. When this type of protection is selected, and the brickwork is thus free to slide the fraction of an inch necessary to relieve the stresses by moving into or out of the expansion joints, it is not necessary to match exactly the expansion joint in the brickwork to the expansion joint, control joint or moving crack in the substrate. If the expansion joint is offset a half a brick from the joint in the substrate, the brick can still move into and out of the expansion joint, and it can function satisfactorily, providing the substrate surface is smooth, and there are no irregularities to anchor it at some point and prevent movement.

It has been learned by sad experience, however, that if the thickness of the brick on the floor is less than 1 in., traffic over it, even light traffic, can flex the brick by pressing it into a soft membrane like asphalt and cause the brick to crack before too long. Therefore, when the brick thickness is to be less than 1 in., the brick is bonded directly to the slab by using a bonding bed joint instead of a membrane and regular bed joint under the brick and over the membrane. These bonding bed joints are usually a nominal $\frac{1}{8}$ in. thick, made of an epoxy resin for high bond strength, and are troweled on the surface as a continuous, uninterrupted layer into which the thin brick or tile is set. All grooves in the back of the tile or brick should be completely filled with the bed material. If this design is to be followed, the concrete substrate should be finished to grade, without low spots, and prepared to receive the bed material just as carefully and to the same specifications and standards as those required for a monolithic surfacing material. This type of bonding bed is very dense, and if applied carefully, in a $\frac{1}{8}$ in. thickness, will, in most cases (but not all), function as a membrane. It is *not* advisable to try to correct holidays, low spots, and other imperfections in the substrate by increasing the thickness of the bed. Epoxies, in particular, are self-leveling resins, and this can cause settlement and sag, resulting in low spots if the tile or brick are set on too thick a bed.

With the tile or brick bonded directly to the substrate, we have in effect

applied a monolithic topping where the tile or brick set in it function like over-size aggregate. From this, it must be apparent that we no longer have a sliding plane under the brick or tile, and so we can no longer offset the expansion joint in the brickwork (or tile) from the joint in the substrate. The former must be exactly above the latter—no matter what this may mean in the cutting of brick to make this fit. Be sure, however, that all cut brick are set back from the expansion joints and only whole brick used on each side.

This also means that stress relief joints will be required on this type of floor to break the lines of stress from the slow growth of the brick or tile, and so prevent disbonding, followed by heaving, just as the stress relief joints in a monolithic floor provide for the cure shrinkage of the monolithic. It should also be remembered that, unlike brick on a membrane, if brick (or tile) are bonded to the substrate, and if the substrate cracks, so will the tile or brick structure.

Determining Floor Thicknesses

As was mentioned above, a brick or tile less than 1 in. thick should not be applied over a soft membrane because traffic will cause it to flex and eventually to crack. In addition, asphalt has cold flow. Thus, a very heavy weight standing permanently at the same spot on an acid brick floor laid over an asphalt membrane, will, after a time, cause the asphalt to squeeze out—cold flow—from under the weight to the area under the adjacent brick. This kind of movement can, if excessive, cause the floor to break up. No two batches of asphalt membrane material are exactly alike, nor are any two areas of the membrane identical in thickness and reinforcing, so it is impossible to make any absolute statements as to the size and weight of acceptable loads. What *can* be said is this: under continuous load—a fixed tank, etc., a permanently parked heavy vehicle (the worst case would be something like a steam roller)—the probable load limit for a $\frac{1}{4}$ in. thick asphalt membrane with a single layer of reinforcing glass fabric is probably about 25 lb/in².

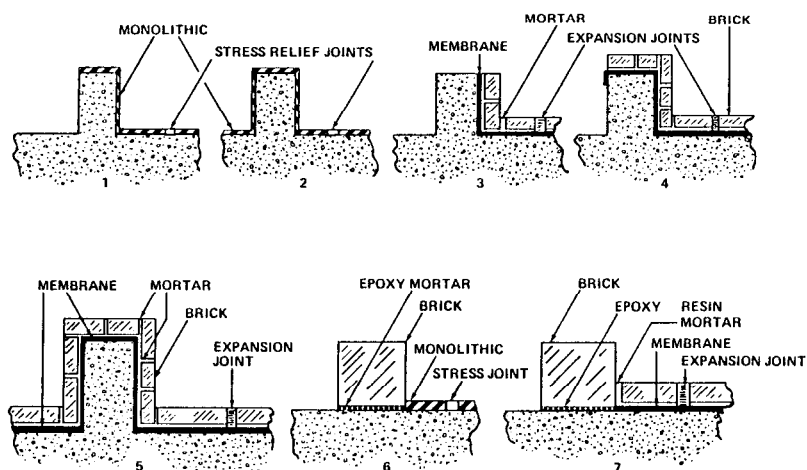
To translate this figure into the conditions in a specific case, the following factors should be borne in mind:

- (1) The height of the load above the membrane. (With a vehicle, this means the distance between the face of the wheel and the center of the axle, plus the thickness of the brick and the thickness of the bed joint.)
- (2) A pinpoint load on the brick itself will spread the load laterally around the joint in a cone pattern as the stress passes through the thickness of the brick. We cannot be exactly sure of this load distribution because of the nature of the brick and its composition, but we can assume as probably worst case a 30° angle from the vertical at the apex directly at the point of load. The higher this load can be elevated, the more it can be spread out. This can be done in two ways: (1) increase the thickness of the brick (which at the same time adds more shear strength and less flexibility to the structure) and (2) use larger diameter wheels with wide faces and preferably large pneumatic tires.

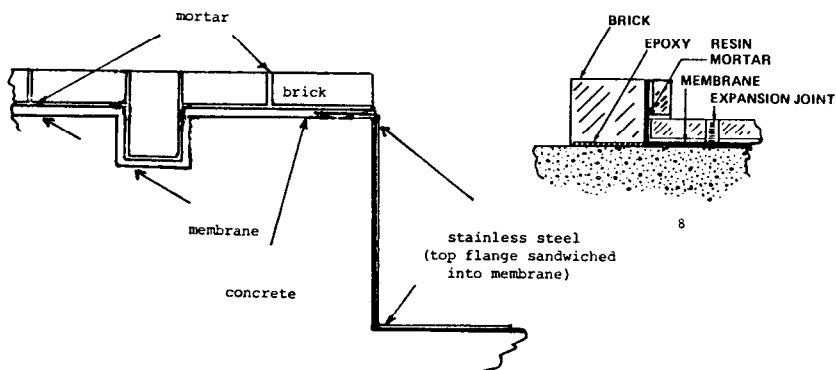
Anticipate, therefore, in your design, the worst load conditions and plan for them. Under column supports or tank pedestals where heavy loading is anticipated, do not use soft membranes, and plan instead on bonded construction. Where you are concerned only with traffic and standing loaded vehicles, be sure that you have adequate brick thickness to accommodate it without breaking up.

Curbs

Curbs are included in floor designs usually to retain spills and to prevent flooding of adjacent areas. For this reason, the usual curb design is like that in Sketches 1 through 5 of Drawing 15. A curb is formed into the floor construc-



The above, "Chemical Resistant Masonry", W. L. Sheppard, Jr. (1982).



Drawing 15

tion when the floor is laid, and the reinforcing is continuous throughout. The membrane is continued along the floor to the curb, up the side and across the top to the other side. This design stays liquid-tight, and is the most suitable for those areas where there may be frequent spills and large volumes of liquid. Where it may be desirable to localize a spill, but there is not too much concern if some small amount of the liquid reaches the outside of the curbed area, setting double brick into the floor as a barrier wall extending above the normal floor surface might handle the matter (Sketches 6 and 7). If the floor is an old one, or it is desired to add a curb to a new floor, one can be created by following the design in Sketch 7. Here, double brick are bonded with an epoxy mortar to the concrete substrate to build the curb. The asphalt membrane is then laid up to this brick curb, and the floor laid over the membrane and bonded to the brick curb just built. Obviously, without a membrane on the face of the brick curb, this curbed area will probably leak through the curb. If we want to stop such a leak, the membrane can be carried up from the floor to the top of (Sketch 8), and over, the brick curb, in effect modifying the design to equate with that of Sketch 4.

Walls Subject to Spray or Splash

In chemical plants where corrosive, wet conditions are anticipated, walls are protected with membranes and brick veneers in the same manner as floors. Alternatively, a divider wall between two rooms, or one that is to support a roof or other load, may be built entirely of "acid brick" and mortar. A different, more attractive system, is usually followed in food plants such as dairies, often employing glazed tile or block. The latter are laid just as are regular cement block, except that the face joints are left void to a depth of $\frac{1}{4}$ in. or more, or raked back to that depth before the joints set up. After cure, the surfaces of the joint are cleaned usually with dilute hydrochloric acid, and the joints pointed full with a furan mortar. See Drawing 14 to see how this kind of a wall is mated to an "acid brick" floor and membrane.

Tile*

Tile, rather than brick, is often used where (1) the designer is dealing with fixed elevations and doesn't have the room to accommodate brick thickness, and/or (2) where appearance is paramount and a "show floor" is wanted. The designer should carefully read those portions of this book that cover tile and brick before deciding which to use, and certainly before he starts detailing the structure. Although they are similar in nature, tile and brick will not provide identical end products, will not accept identical conditions, and are not installed in the same manner.

Tile has been used for decorative purposes for thousands of years. Of the many types manufactured, three varieties are most frequently employed in chemical service: (1) Quarry tile, which much resembles a thin brick, most often used in laboratories, kitchens and food plants; (2) Ceramic tile, small, thin,

*See W.L. Sheppard, Jr., *Chemically Resistant Masonry*, 2nd Ed., Marcel Dekker, NYC, pp 55-58 (1982).

often $\frac{1}{4}$ to $\frac{3}{8}$ in. thick vitrified shapes, usually supplied mounted on an open weave cloth or paper backing, laid in sheets on a semisoft bed, which is allowed to cure, then the backing removed and the balance of the open joints filled by grouting; (3) Glazed tile, which can be a multitude of sizes and shapes such as 4 in. by 4 in. porcelain bodies with a glazed face, or even ceramic blocks of which one face has a fired glaze. These are most often used in areas that must be kept very clean, the smooth glaze making it easier to sanitize and disinfect.

Unlike brick, which are buttered on the contact faces with mortar and then laid, tilesetters have, for hundreds of years, prepared a semisoft bed—most often of portland cement and sand—and set the tile in it, laying a straight edge over it and tapping the straight edge to adjust the elevations of all the tile to provide a uniform, level, surface. Concrete contractors are accustomed to supplying the tilesetter with a rough slab on which to place the bed, and in many cases applying a "waterproofing" layer of paper and low temperature asphalt to the slab before the bed is placed. No matter what "grout" (a loose mortar mix "grouted" into the open joints after the bed has set and anchored the tile in place) is used with the tile, this design is not adequate for wet chemical service, under dilute conditions with weak corrosives. All hydraulic materials must be replaced with materials that are chemically resistant, and the "waterproofing" must be replaced by a sound, liquid-tight membrane, if this tile floor is to have an economic life.

This means that the designer must make certain that his specifications are not misunderstood. He must carefully specify what the exact surface of the slab must be in order to be accepted, exactly what membrane shall be used instead of the waterproofing and how it shall be installed, exactly what bedding material shall be used to set the tile, and exactly what "grout" shall be used in the open joints. If a thin bed is to be used to bond the tile directly to the concrete substrate, he must indicate acceptable thicknesses for it and specify that the application is to be made with a flat trowel—*not* a ribbed or serrated one that will lay ribbons of bed rather than a smooth, continuous, void-free bed on the concrete. All materials should be identified generically so that there is no mistake and so that if later another product said to be "equal" is substituted, the installer will be able to determine whether it is indeed equal.

SUBSTRATE

A separate section of this book discusses the selection and design of substrate structures which are required to support chemically-resistant masonry. This section will not duplicate what appears therein, except to warn the designer of three things. (1) The designer must verify that the substrate selection and design are adequate to provide the necessary support for the full load anticipated with a safety factor of not less than $1\frac{1}{2}$, without visible deflection. (2) He must check with the materials manufacturers and installers of all the materials he has selected which will be in direct contact with the substrate to determine what surface strength and surface preparations of the substrate should be provided, and then be certain that these requirements are included in his specifications. (3) He must verify that there is nothing in the materials that will be in contact

with the substrate that can interact with anything in the selected substrate to prevent full cure and/or adequate adhesion from taking place.

This third item is often overlooked. The following are examples. Some admixtures, curing agents, air entrainment agents, and other materials added to concrete mixes can react with and deplete the curing agents in epoxy toppings and bonding agents, preventing adequate cure and resulting in disbondment. Furan and phenolic mortars use acid curing agents. If they are placed directly against carbon steel and/or concrete, the acid curing agent can react with the substrate depleting it in the surface layer and preventing full cure. When pointing joints in portland cement-bedded quarry tile with a furan mortar, it is customary first to paint the portland cement joint face with muriatic acid, which prevents the depletion of the hardening agent and accelerates the cure. Heat applied to the carbon steel surface can accelerate the hardening of the mortar before the surface reaction can deplete the hardener, and so ensure fast and complete cure and a bond to the substrate. These are but two examples. Be *sure* that the manufacturers of the materials accept your specifications as clear and concise, and as protection against any such incompatibility.

Lastly, in concrete construction, all vertical sections are poured against forms. Contractors lubricate forms to prevent adhesion of the concrete to the forms. Be certain that the lubricant or form release materials used are compatible with the materials to be installed and acceptable to their manufacturers and applicators. If they are not, your specification must include provision for removing, probably by brush sandblast, any residue left on the surface of the concrete after the forms are removed as well as provision for inspection to insure uniformity and integrity of the structure. The use of a solvent to remove oil or grease from the surface of formed concrete is not recommended since it drives some dissolved material into the concrete surface.

SIDE EFFECTS

Galvanic Corrosion of Lead and Stainless Steel Due to Proximity to Carbon and Carbon-Filled Mortars and Grouts

Years ago, college chemistry textbooks used to contain tables listing in order of electrical potential the metallic elements and carbon. For some odd reason, the tables used in schools and colleges today omit carbon. This is even more strange because the most common of the dry cell batteries until only a few years ago, made use of the electrical potential between zinc and carbon—a relationship illustrated by the table. Reproduced below are two such tables, one of which includes carbon.

Table 45-2 is taken from John Schley's paper published in 1974 by *Chemical Engineering*. I have been unable to locate any of the old textbooks that showed carbon in relation to the metallic elements. Table 45-3 is from a college textbook currently in use. Note that there is disagreement in the relative order of some of these metals (due to the differences noted in oxidizing and reducing environments), particularly in the placement of aluminum. However, this does not alter the relationship between carbon and these metals. The reader will observe, however, that when stainless steel (18-8) is passivated, it becomes

more "noble"—very close to silver and graphite, while if *not* passivated, it is close to lead in potential.

Table 45-2: Galvanic Series of Metals and Alloys

Anodic or least noble
Magnesium
Zinc
Aluminum 25
Cadmium
Steel or iron
Cast iron
Ni-resist
18-8 Cr-Ni-Fe (active)
Hastelloy alloy C
Lead
Tin
Nickel (active)
Inconel (active)
"Hastelloy" alloy A
"Hastelloy" alloy B
Brasses
Copper
Copper nickel alloys
Titanium
Monel
Nickel (passive)
Inconel (passive)
18-8 Cr-Ni-Fe (passive)
Silver
Graphite
Cathodic or most noble

Table 45-3: Galvanic Series

Element	Potential Difference Electrode-Electrolyte	Element	Potential Difference Electrode-Electrolyte
Potassium	-3.20	Hydrogen	0.000
Sodium	-2.82	Arsenic	<+0.293
Barium	-2.82	Copper	+0.329
Strontium	-2.77	Bismuth	<+0.391
Calcium	-2.56	Antimony	<+0.466
Magnesium	-2.54	Mercury	+0.750
Aluminum	-1.276	Silver	+0.771
Manganese	-1.075	Palladium	<+0.789
Zinc	-0.770	Platinum	<+0.863
Cadmium	-0.420	Gold	<+1.079
Iron	-0.340	Fluorine	+1.96
Thallium	-0.322	Chlorine	+1.417
Cobalt	-0.232	Bromine	+0.993
Nickel	-0.228	Iodine	+0.520
Tin	<-0.192	Oxygen	+1.119
Lead	-0.148		

From these tables, it will be apparent to anyone who has studied elementary chemistry that if a piece of carbon and a strip of lead or of unpassivated stainless steel are placed in a beaker containing an electrolyte (e.g., a 10% solution of table salt), the metal will become anodic (positive) to the carbon, and will start to "waste."

Of the metals in the table, lead and stainless steel are the most frequently used in chemical service: lead as a membrane liner for steel process equipment, stainless steel as the material from which to make agitators or other internals. As explained elsewhere in this volume, it is common practice to place a brick lining inside of a lead-lined process vessel to provide thermal insulation, reducing the skin temperature of the lead to 160°F or lower. If the contained liquid contains acid fluorides to a concentration of 50 ppm of HF equivalent, it is normal to select a carbon brick as a liner, and to use a carbon-filled mortar in which to bed and lay up the brick. Most of such process vessels will contain electrolytes, so it will be apparent that by this lining design, an electrolytic cell is set up in which the lead will be slowly wasted and penetrated. To prevent this from occurring, it is necessary to insert a "voltage breaker" between the lead and the carbon brick. This is done in one of several ways. The most common is to substitute for the carbon-filled mortar one that employs a nonconductor filler, but which will not be attacked by hydrofluoric acid. For this purpose, a mortar containing barytes (barium sulfate) is recommended. Alternatively, a sheet of fluorocarbon resin (such as Teflon® FEP), 5 mils or more thick, may be laid over the lead lining, and the brickwork laid over the fluorocarbon. In some cases, both precautions have been taken. If a stainless steel agitator is to be used, it should be passivated and kept as far as possible from the carbon brick lining.

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Brick Growth

In all designs involving "acid brick," provision must be made for the irreversible growth of North American brick which takes place over an extended period. This growth or "swelling" was not much noted in "acid brick" prior to about 1954, when manufacturers stopped using "beehive" ovens and started using continuous kilns.

A check of the Bibliography will show the reader that growth (or swelling) of face brick, used for ordinary commercial and industrial construction has been observed for half a century and more. The literature indicates, beyond general

observations, that the amount of "swelling" and the speed with which it takes place results from water absorption of the clays from which the brick are made, and that it bears some relation to the temperature of firing of the brick. Little has been done in refined testing to eliminate the variables, to determine what, if any, relationship exists to the exact temperature of the firing, together with the duration of firing, and to any phase changes that may take place in the composition of the body of the brick. It is noted, however, that brick which are "restrained" expand (swell or grow) less than those that are not subject to loading or restraint.

It has been noted that steel cylindrical tanks lined with "acid brick," have in some few cases actually been split apart, apparently by stresses resulting from this brick growth. On the other hand, where the steel was fabricated of heavy, well-reinforced metal, the brick have grown only until they were tightly pressed against and into the membrane, after which growth stopped. When a single brick in such a lining was damaged by a blow or in some other manner, and had to be replaced, it was noted that upon its removal and the release of the restraint that brick had supplied, the brick on all sides grew or swelled slightly into the void, so that a replacement brick always had to be trimmed on all four sides to fit into the same space. One of the same size as the brick that was removed could not be used. Exactly where the stresses of growth are balanced off against the restraint, no one has yet determined, although at least one company has a project under development to plant strain gauges in such linings to determine what pressures are reached before equilibrium is attained.

We *do* know that most hard burned, low absorption "acid brick," meeting Specification ASTM C-279, will grow irreversibly over an extended period of time by approximately 0.16% of any dimension. We also know that such growth takes place more slowly under cold, dry, static conditions, and most rapidly in hot, wet, cycling exposures. We have also noted that brick with the higher absorption—ones outside the limits of Type L—seem to expand more than the 0.16% limit, and that this growth appears to be more noticeable with the lower firing temperatures and the shorter kiln time. However, without conclusive test data, checking the effects of all variables individually, no absolutes are available, and only generalizations can be made.

In design, it is important always to plan to accommodate this growth, based on the normal 0.16%, especially on flat surfaces like floors, with adequate expansion joints, or, where suitable, such as in cylindrical designs, by adequate restraint. Failure to do so can result in "humping" (bulging upward or outward) of flat surfaces, or rupturing the walls of inadequately designed cylindrical vessels.

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NOTE: To determine lining *thickness*, number of layers of brick and selection of types, to insulate membranes, see mathematics in Chapter 47, and especially *Editor's Note*, page 623.



Figure 45-1: Example of a contoured wall tank. See Drawing 1

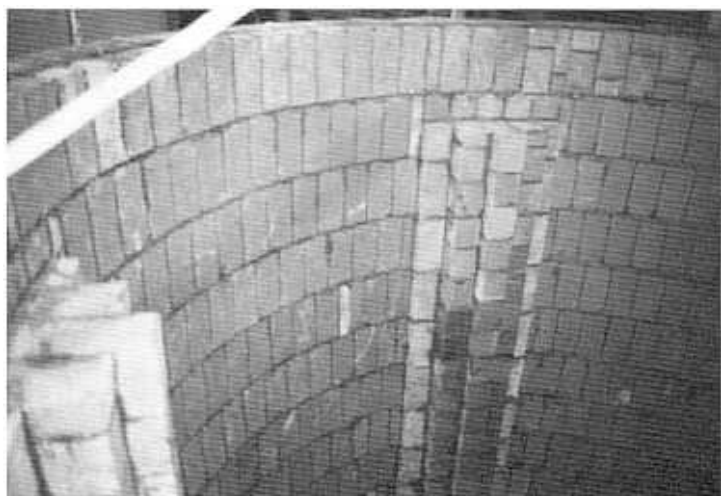


Figure 45-2: Illustration of a baffle built into the brick vessel wall. See Drawing 12, Sketch 2



Figure 45-3: One of the earliest acid-resistant tile floors in a brewery pasteurizer room (1940), laid in a portland cement bed with a phenolic resin mortar grout.

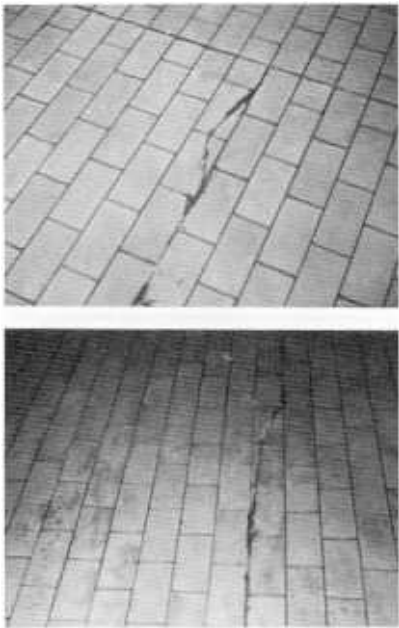


Figure 45-4: Examples of floors laid with high bond, high strength furan mortar in which cure shrinkage of the mortar has caused the brick to break. The cracks so created have been filled with expansion joint sealant. See Chapter 25.



Figure 45-5: Steel floor plate plant in the cold storage room of a dairy. The steel plates are cemented to the concrete substrate with an epoxy adhesive.



Figure 45-6: Example of what happens if a designer makes no provision for brick growth and designs substrate surface flat instead of curved (see Drawing 1). Note the pilaster, supposed to strengthen the wall, was completely ineffectual.

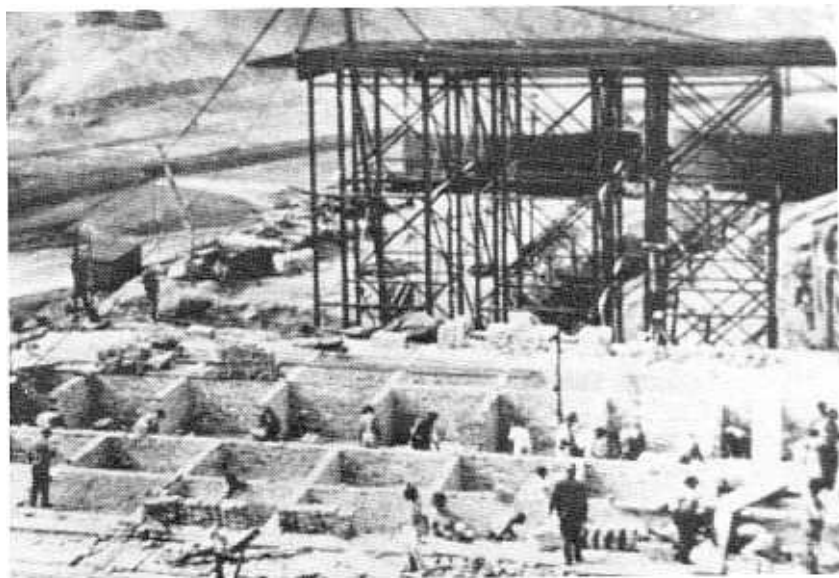


Figure 45-7: Building the "Isabel" H_2SO_4 chamber plant at Copper Hill, Tennessee, 1916-18, using the first fast-setting sodium silicate mortar, DURO®.



Figure 45-8: In a modern food plant, a properly designed and laid floor tile (8 in. $\times$ 3 $\frac{3}{4}$ in. $\times$ 1 $\frac{5}{16}$ in.) floor, using a $\frac{1}{4}$ in. thick glass cloth-reinforced hot asphalt membrane and a furan resin bed and grout. Note the flexibilized epoxy expansion joint.